Comparison of visual and refractive outcomes between hydrophilic and hydrophobic trifocal intraocular lenses sharing the same optical design

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Purpose: To compare clinical outcomes between two trifocal intraocular lenses (IOLs): the new FineVision POD F GF trifocal IOL made of hydrophobic acrylic glistening-free material, and the FineVision POD F IOL made of hydrophilic acrylic material with 26% water uptake in patients undergoing routine cataract surgery using standard phacoemulsification.

Setting: Semmelweis University, Department of Ophthalmology, Budapest, Hungary.

Design: Prospective controlled randomized single-center single-surgeon study.

Methods: Each patient had the hydrophilic POD F IOL implanted in one eye and the hydrophobic POD F GF IOL in the contralateral eye, according to a randomization table. Clinical outcomes included distance (4 m), intermediate (70 cm), and near (35 cm) visual acuities, contrast sensitivity measured under photopic and mesopic conditions, and defocus curves under photopic conditions. The follow-up was 6 months.

Results: The study comprised 25 patients. Under photopic conditions, there was no statistically significant difference between POD F GF and POD F IOLs for uncorrected distance (UDVA) \( (P = .607) \), uncorrected intermediate (UIVA) \( (P = .491) \), and uncorrected near (UNVA) \( (P = .414) \) visual acuities. Under mesopic conditions, there was no statistically significant differences between the 2 IOLs for UDVA \( (P = 1.00) \), UIVA \( (P = .149) \), and UNVA \( (P = .551) \). No statistically significant differences in contrast sensitivity were found between the groups under photopic \( (P = .4347) \) and mesopic \( (P = .425) \) conditions. No safety issues were reported.

Conclusion: The study demonstrated equally good visual and refractive outcomes for the POD F GF IOL and the POD F IOL, giving the surgeon the option to choose the preferred material for the individual patient without compromising clinical outcomes.

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Trifocal intraocular lenses (IOLs) were developed to address limitations of bifocal IOLs at intermediate distances. Bifocal IOLs have two focal points (near and far), leading to concerns that the quality of vision at intermediate distances might prove inadequate for functioning in daily life routines, such as reading and computer work. A second concern was that photic phenomena (glare, halos, and positive or negative dysphotopsia) occur more frequently with multifocal IOLs than monofocal IOLs.

The FineVision trifocal IOL optic (PhysIOL S.A.) was developed to overcome such limitations. It uses a trifocal design by combining two diffractive patterns, one with a +3.5 diopters (D) addition for near vision and the other with a +1.75 D addition for intermediate vision. The diffractive steps are alternated over the optical zone. The FineVision optic design is currently used in the POD F IOL, which is a 26% hydrophilic acrylic IOL with a double C-loop haptic design. Studies have demonstrated that the POD F IOL provides good safety and efficacy as well as improved quality of vision at intermediate distances.

Recently, Physiol developed the POD F GF IOL, which also uses the FineVision optic and the double C-loop haptic but differs in material composition. The optics of the two IOLs are designed in such a way that the measurable properties (eg, near addition powers) are as similar as possible.
under laboratory conditions (e.g., optical bench measurements). Nonetheless, because the materials are different (e.g., different refractive indices and different Abbe numbers), the thickness and surfaces of the IOLs differ significantly. The POD F GF uses the hydrophobic acrylic glistening-free (GFree) raw material, which is designed to overcome the disadvantages of both traditional hydrophobic and hydrophilic IOL materials. Indeed, it is known that hydrophobic acrylic IOLs are associated with an increased risk for glistening formation, but usually provoke low or no posterior capsule opacification (PCO), whereas hydrophilic IOLs resist glistening formation, but are more likely to have the complication of PCO.

The current study set out to compare visual and refractive outcomes between the hydrophobic trifocal IOL (POD F GF) and the hydrophilic trifocal IOL (POD F), and investigate whether the newer POD F GF can achieve outcomes as good as the existing POD F. Although the optical properties of the POD F GF IOL have been previously reported, to our knowledge, this is the first study reporting clinical outcomes for the POD F GF.

MATERIALS AND METHODS

Study Design

The study was a prospective randomized controlled single-surgeon comparative study performed in patients undergoing cataract surgery using standard phacoemulsification. Each patient had the POD F IOL implanted in one eye and the POD F GF IOL implanted in the contralateral eye. The choice of IOL in each eye of each patient was determined according to a randomization table. The study conformed to ethics codes based on the tenets of the Declaration of Helsinki and was approved by the Semmelweis University, Department of Ophthalmology, Budapest, Hungary. All patients had surgery between November 2016 and July 2017.

The study conformed to ethics codes based on the tenets of the Declaration of Helsinki and was approved by the Semmelweis University Regional and Institutional Committee of Science and Research Ethics Committee (approval number 125/2016). All patients signed an informed consent form.

Patients

Suitable patients fulfilled the following inclusion criteria: cataractous eyes with no comorbidity, age 50 years or older, and regular corneal astigmatism less than 0.75 D. Exclusion criteria included: irregular astigmatism, acute or chronic disease or illness that would increase risk or confound study results, history of ocular trauma or previous ocular surgery, and complicated surgery.

Intraocular Lenses

Table 1 shows the descriptive qualities of the POD F GF and POD F. Both IOLs use the same haptic and optic designs. The haptic consists of a double C-loop for optimization of effective lens position (tilt, shift, and rotation), whereas the optic bears a diffraction trifocal element on the anterior side allowing presbyopia correction for near and intermediate vision. However, the POD F GF and POD F IOLs differ in their materials and affinity for aqueous environments as follows:

- The POD F GF IOL, which uses the GFree material, has a limited water uptake (4.9%) after conditioning, allowing the water content of the IOL to equilibrate before implantation. The refractive index of the material is 1.525.
- The POD F IOL is made of 26% hydrophilic acrylic copolymer. The refractive index of the material is 1.46.

Surgical Procedure

The surgeries were performed by a single surgeon (Z.Z.N.) at Semmelweis University, Department of Ophthalmology, Budapest, Hungary. All patients had surgery between November 2016 and July 2017.

Standard routine cataract surgery was performed. For phacoemulsification, a 2.2 mm corneal incision was made. A 5.5 mm diameter capsulorhexis was targeted to allow the optic to be fully overlapped by the anterior capsular rim. A sodium hyaluronate 1.2% ophthalmologic viscosurgical device (OVD) (Amvisc, Bausch & Lomb UK Ltd) was used to avoid bias. The same injector (Accuvject 2.1, Meditel AG) was used for both IOLs to limit the variability of the stress exerted on the incision and acted to standardize the surgically induced astigmatism.

Preoperative and Postoperative Assessments

Examinations were performed preoperatively, on the day of surgery, and at 1 day and 1, 3, and 6 months postoperatively.

The distance visual acuities were measured at 4 m using Early Treatment Diabetic Retinopathy Study (ETDRS) charts under controlled lighting levels of 85 candelas (cd)/m² for photopic conditions and 3.5 cd/m² for mesopic conditions. The intermediate visual acuities were measured at 70 cm, and the near visual acuities were measured at 35 cm using ETDRS near charts under controlled mesopic and photopic lighting levels. All visual acuity measurements were done monocularly.

The postoperative examinations at the 1-month, 3-month and 6-month visits included manifest refraction, uncorrected (UDVA) and corrected (CDVA) distance visual acuities, and distance-corrected intermediate (DCIVA) and near (DCNVA) visual acuities under photopic conditions. Other measurements included applanation tonometry intraocular pressure, corneal keratometry, biometry (IOLMaster, Carl Zeiss Meditec AG), and slitlamp evaluation.

The defocus curve was measured at the 3-month postoperative visit with the best spherocylindrical refraction in place, using ETDRS charts at 4 m for defocus values between −5.00 D and +2.00 D.

Contrast sensitivity was measured at the 3-month visit under both photopic and mesopic conditions using the CSV-1000 HGT (VectorVision, Inc.) at the 3, 6, 12, and 18 cycles per degree (cpd) frequencies.

Statistical Analysis

A sample size calculation indicated that to detect a difference in CDVA of 0.08 logarithm of the minimum angle of resolution (logMAR) between the two groups, with a power of 90%, a minimum of 22 eyes per group was required. To account for loss to follow-up, 25 eyes were included in each group.

Descriptive statistical analysis was performed using the Excel software tool (version 2016, Microsoft Corp.). The mean values, median, range, and standard deviations (SDs) were calculated for all preoperative and postoperative parameters.

A repeated-measures analysis of variance (ANOVA) was computed using Stata software for Windows (StataCorp LLC) to compare the two groups for visual and refractive outcomes; a post-hoc Tukey test was performed once the repeated-measures ANOVA F test rejected the hypothesis of equal average values in each group. A one-way ANOVA was used to compare the defocus
curve and contrast sensitivity in the two groups. The level of significance was a $P$ value less than .05.

**RESULTS**

**Demographics**
The study comprised 25 patients undergoing routine cataract surgery who had the POD F GF IOL implanted in one eye and POD F IOL implanted in the contralateral eye between November 2016 and July 2017. The patients’ mean age on the day of surgery was 58.8 ± 7.8 years (range 43 to 78 years). There were 15 women (60%) and 10 men (40%), and 12 POD F IOLs (48.0%) were implanted in the dominant eye compared with 13 POD F GF IOLs (52.0%). All the patients were white and available for follow-up at 6 months.

There were no statistically significant differences in preoperative biometry and keratometry data between the two eyes of the patients.

**Monocular Distance Visual Acuity**

Table 2 shows the mean preoperative and 6-month postoperative UDVA for both photopic and mesopic conditions. Postoperatively, there was no statistically significant difference in CDVA between eyes treated with POD F and eyes treated with POD F GF under photopic ($P = .879$) and mesopic ($P = .845$) conditions. There was no statistically significant change in CDVA between 1 month and 6 months postoperatively in both groups ($P > .05$), under photopic ($P > .05$) and mesopic ($P = .126$) conditions, indicating that the CDVA was stable.

**Monocular Uncorrected Intermediate Visual Acuity**

Table 2 shows the mean preoperative and 6-month postoperative UIVA for both photopic and mesopic conditions. There was no statistically significant difference in UIVA between eyes treated with POD F and POD F GF under photopic ($P = .491$) and mesopic ($P = .149$) conditions. There was a statistically significant improvement in UIVA under photopic conditions in both groups between 1 month and 3 months postoperatively ($P = .018$), and between 1 month and 6 months postoperatively ($P = .010$), although the photopic UIVA was found to be stable between 3 months.
and 6 months postoperatively \((P = .975)\). There was no statistically significant change in UIVA between 1 month and 6 months postoperatively in both groups under mesopic conditions \((P = .382)\).

**Monocular Distance-Corrected Intermediate Visual Acuity**

Table 2 shows the mean preoperative and 6-month postoperative DCIVA for both photopic and mesopic conditions. There was no statistically significant difference in DCIVA between eyes treated with POD F and eyes treated with POD F GF under photopic \((P = .947)\) and mesopic \((P = .677)\) conditions. The mean DCIVA under photopic conditions was approximately 1 line better than under mesopic conditions in both groups. There was a statistically significant improvement in both groups across all postoperative visits when compared with the preoperative DCIVA \((P < .001)\). The DCIVA under photopic and mesopic conditions was stable across visits from the 1-month to 6-month follow-up visits \((P > .05)\).

Figure 1, C, shows the cumulative distribution of DCIVA under photopic conditions in both groups. At 6 months postoperatively, the DCIVA was 20/25 or better in 20 eyes (80%) in the POD F group and in 22 eyes (88%) in the POD F GF group. The DCIVA was 20/32 or better in all eyes. Figure 1, D, shows the cumulative distribution of DCIVA under mesopic conditions in both groups. At 6 months postoperatively, the DCIVA was 20/32 or better in 22 eyes (88%) in the POD F group and in 23 eyes (88%) in the POD F GF.
(92%) in the POD F GF group. The DCIVA was 20/40 or better in all eyes.

**Monocular Uncorrected Near Visual Acuity**

Table 2 shows the mean preoperative and 6-month postoperative UNVA for both photopic and mesopic conditions. There was no statistically significant difference in UNVA between the two groups under photopic \((P = .414)\) and mesopic \((P = .562)\) conditions. There was a statistically significant improvement in both groups in photopic UNVA between 1 month and 3 months postoperatively \((P = .037)\) and between 1 month and 6 months postoperatively \((P = .015)\). The photopic UNVA was stable from 3 months to 6 months postoperatively \((P = .941)\). There was no statistically significant change in UNVA between 1 month and 6 months postoperatively in both groups under mesopic conditions \((P = .551)\).

**Monocular Distance-Corrected Near Visual Acuity**

Table 2 shows the mean preoperative and 6-month postoperative DCNVA for both photopic and mesopic conditions. There was no statistically significant difference in DCNVA between the two groups under photopic \((P = .974)\) and mesopic \((P = .494)\) conditions. The mean DCNVA under photopic conditions was approximately 1 line better than under mesopic conditions in both groups. There was a statistically significant improvement in both groups across all postoperative visits when compared with the preoperative DCNVA \((P < .001)\) for both photopic and mesopic conditions. The DCNVA was stable across visits from the 1-month to 6-month follow-up \((P > .05)\) under both photopic and mesopic conditions.

**Figure 1, E**, shows the cumulative distribution of DCNVA under photopic conditions in both groups. At 6 months postoperatively, the DCNVA was 20/25 or better.
in 19 eyes (76%) in the POD F group and in 23 eyes (92%) in the POD F GF group. The DCNVA was 20/32 or better in all eyes. Figure 1, F, shows the cumulative distribution of DCNVA under mesopic conditions in both groups. At 6 months postoperatively, the DCNVA was 20/32 or better in 17 eyes (68%) in the POD F group and in 20 eyes (80%) in the POD F GF group. The DCNVA was 20/40 or better in 24 eyes (96%) in the POD F group and in all 25 (100%) eyes in the POD F GF group.

Refractive Accuracy

Manifest Sphere The mean postoperative manifest sphere at 6 months postoperatively was 0.22 ± 0.30 (range 0.00 to +1.00 D) in the POD F group, and 0.14 ± 0.32 (range −0.50 to +0.75 D) in the POD F GF group. There was no statistically significant difference in manifest sphere between the two groups (P = .477). There was a statistically significant improvement in both groups across all postoperative visits when compared with the preoperative manifest sphere (P = .008 at 1 month, P = .002 at 3 months, and P = .003 at 6 months). The sphere was stable between 1 to 6 months postoperatively (P > .05).

Cylinder Component The mean manifest cylinder at 6 months postoperatively was −0.30 ± 0.47 (range 0.00 to −1.75 D) in the POD F group, and −0.18 ± 0.41 (range 0.00 to −1.75 D) in the POD F GF group. There was no statistically significant difference in cylinder between the two groups (P = .719). There were no statistically significant differences in cylinder between the preoperative and all postoperative visits (P = .404). Figure 2 shows the distribution of refractive cylinder at 6 months postoperatively; 22 eyes (88%) were within ±0.50 D of zero in both groups, and 23 eyes (92%) and 24 eyes (96%) were within ±1.00 D of zero in the POD F and POD F GF groups, respectively.

Manifest Refraction Spherical Equivalent The manifest refraction spherical equivalent (MRSE) at 6 months postoperatively was 0.07 ± 0.19 (range −0.38 to +0.50 D) in the POD F group and +0.05 ± 0.21 (range −0.50 to +0.50 D) in the POD F GF group. There was no statistically significant difference in MRSE between the two groups (P = .500). There was a statistically significant improvement in both groups across all postoperative visits when compared with the preoperative MRSE (P = .004 at 1 month, P = .002 at 3 months, and P = .004 at 6 months postoperatively). The MRSE was stable across visits from the 1-month to 6-month follow-ups (P > .05). Figure 3 shows the distribution of MRSE at 6 months postoperatively; all eyes were within ±0.50 D of the target refraction in both groups.

Defocus Curve

Figure 4 shows the defocus curves in both groups. There was no statistically significant difference between the two groups (P = .980). The visual acuity was 20/32 or better in both groups over a 3.00 D range between +0.50 D and −3.00 D. At the intermediate range, there was no decrease in visual acuity, with values remaining within one-half of a line of visual acuity measured at the near range.

Contrast Sensitivity

Figure 5 shows the contrast sensitivity for both photopic and mesopic conditions. There were no statistically significant differences between the two groups for photopic contrast sensitivity (P = .61) or mesopic contrast sensitivity (P = .424).

Safety Assessment

No safety adverse events or serious adverse events occurred during the study for either IOL. At the 6-month follow-up, no glistening was observed in any of the IOLs and no neodymium:YAG (Nd:YAG) laser posterior capsulotomies were performed or planned. All IOLs except one (POD F) were well centered. However, the slight decentration did not lead to a significant impact on the visual acuity outcomes. The fundus and anterior chamber in all eyes were rated as normal.

DISCUSSION

This study demonstrated equally good refractive and visual outcomes, as well as good safety for eyes implanted with both the POD F IOL and the POD F GF IOL, with no
statistically significant differences between the two IOLs. Both IOLs provided excellent results for visual acuities at near (35 cm), intermediate (70 cm) and far (4 m) distances, under both photopic and mesopic conditions. The refractive outcomes indicated excellent refractive predictability, with all eyes within ±0.50 D of the target refraction for both IOLs.

Interestingly, only small differences were found in visual acuity performance of the POD F GF and POD F when measured under photopic and mesopic conditions. The mesopic measurements, neglected in many previous trifocal IOL studies, are important to consider because daily activities, including driving at night and cinema and television watching, are performed under low mesopic luminance. In this study, the mesopic visual acuity was within 1 line of photopic visual acuity at all testing distances: far, intermediate, and near. Under mesopic conditions, the mean visual acuity remained good and was 20/32 or better in both IOL groups at intermediate and near distances.

The uncorrected visual acuity results as well as the excellent refractive stability demonstrated that the IOL power calculations worked well and that spectacle independence would have been achieved with both IOLs at all distances.

In this study, visual acuity was measured at 3 postoperative timepoints (1 month, 3 months, and 6 months). At distance, uncorrected visual acuity was stable across time from the 1-month visit. In contrast, at the near and intermediate distances, the results for both IOLs showed that uncorrected visual acuities under photopic light conditions showed improvements between 1 month and 3 months and between 1 month and 6 months. The explanation for such differences is likely to be that neuroadaptation takes longer for near and intermediate distances than far distances. Such findings demonstrate that the POD F GF neuroadaptation is in keeping with the time observed for neuroadaptation with other FineVision IOLs, which is typically 3 months and faster for other multifocal IOLs.

No safety-related issues were found with either IOL, although results regarding glistenings and PCO will need to be monitored over a longer follow-up. At the 6-month timepoint, no glistenings were observed in either group, which was expected based on the preclinical and clinical testing of the hydrophobic acrylic GFree raw material used in the POD F GF. There was no clinically significant PCO in either group at the 6-month follow-up necessitating an Nd:YAG posterior capsulotomy.

In comparing the performance of the POD F and POD F GF with other commercially available multifocal IOLs, in particular, trifocal IOLs, the FineVision IOL...
demonstrated comparable performance to other trifocals on the market at near distances. In the studies reviewed, the mean UNVA across studies was 0.121 logMAR or 20/26 in Snellen equivalent. On distance visual results, the aggregated results showed a mean UDVA of at least 20/32 or better, with 7 studies reporting a mean UDVA better than 20/20. In general, the percentage of patients with UDVA 20/25 or better was good and varied between 64% and 100%. The POD F and POD F GF IOLs in the current study compared favorably with the mean UDVs at 20/20 and 20/25 under photopic conditions and 20/25, on average, under mesopic conditions. At intermediate distances, the mean UIVA across studies was 0.124 logMAR or 20/27 in Snellen equivalent. The reported results indicated a possible trend toward slightly better UIVA for the trifocal IOLs and the FineVision compared with other multifocal IOLs. In the current study, the mean DCIVA was 0.04 ± 0.09 for the POD F GF (equivalent to 20/22) and 0.06 ± 0.09 for the POD F (equivalent to 20/23) in photopic conditions, which is slightly better than the average across published studies. Under mesopic conditions, the DCIVA only decreased by 1 line of visual acuity in both groups and was equivalent to 20/28.

In the prospective studies that enable a direct comparison between the PhysIOL IOLs and other multifocal IOLs, Gundersen and Potvin compared the FineVision with the AcrySof Panoptix IOL (Alcon Laboratories, Inc.) and concluded that both IOLs performed well at all distances with a better intermediate vision at 60 cm for the Panoptix group by 0.5 lines. Martinez de la Casa et al. compared the FineVision with the AT LISA tri 839MP IOL (Carl Zeiss Meditec AG) and reported no statistically significant differences in visual and refractive outcomes between groups.

The possibility of a functional reduction in contrast sensitivity is considered a drawback of multifocal IOL technology. In the current study, contrast sensitivity was good and within the expected range for eyes after IOL implantation with no significant difference observed between the two groups in both photopic and mesopic conditions. Such data are reassuring because multifocal IOLs are known to decrease the amount of light reaching the retina from different foci, which in turn reduces contrast sensitivity. In a previous study with the POD F, Alfonso et al. measured binocular contrast sensitivity under both photopic and mesopic conditions. Our findings are consistent with their findings under both photopic conditions at all frequencies and mesopic conditions at higher frequencies, and possibly slightly lower for the 3 cpd and 6 cpd frequencies under mesopic conditions. This could be attributed to the fact that measurements in the current study were performed monocularly, whereas Alfonso et al. reported binocular results.

In terms of quality of vision, visual disturbances (halos or glare) are a known complication of multifocal IOLs; however, several studies have demonstrated some neural adaptation to the multifocal IOLs with a decrease in visual disturbances over time. It was not possible to assess subjective quality of vision in this study because of the nature of the comparative study design, requiring each patient to receive the POD F IOL in one eye, and the POD F GF IOL in the contralateral eye. This study design also prevented any binocular assessment of the IOLs. A quality of vision assessment and binocular outcomes will be the subjects of a future study in which patients will have the same IOL implanted bilaterally. The advantage of the current design was to minimize any bias in the comparison of the two IOLs. Another study is currently being undertaken to compare the clinical outcomes for the POD F GF IOL and the POD F IOL in Asian eyes.

Another limitation of this initial study is that the outcomes were reported in a relatively small sample group and for a follow-up of 6 months. Additional studies are currently being performed with larger cohorts and longer-term follow-ups to confirm these findings and compare the incidence of PCO and glistenings with both IOL materials.

In conclusion, this study demonstrated good visual and refractive outcomes with the new hydrophobic POD F GF compared with the existing hydrophilic POD F. Both IOLs allow for safe and efficient restoration of near, intermediate, and far visual acuity for cataract patients undergoing IOL implantation. The POD F GF IOL is unique in combining the benefits of the trifocal FineVision technology, double C-loop haptic design, and GFree material. This combination of features has the potential to allow patients to benefit from increased spectacle independence for vision at all distances as well as additional benefits associated with the hydrophobic material, such as a reduced risk for postoperative glistenings and PCO. The POD F GF IOL offers surgeons a new opportunity to implant an IOL consisting of a trifocal diffractive optic in combination with a hydrophobic glistening-free material. This opportunity might be interesting for surgeons preferring hydrophobic over hydrophilic materials.

WHAT WAS KNOWN
- The hydrophilic POD F intracocular lens (IOL) (PhysIOL S.A.), using the double C-loop haptic, has been shown to provide good far, intermediate, and near visual acuities with high rates of patient satisfaction and good refractive predictability.
- The hydrophobic acrylic glistening-free (GFree) material is a new generation material, specifically designed to overcome glistening formation and posterior capsule opacification.
- The new hydrophobic POD F GF IOL combines three PhysIOL proprietary technologies: the trifocal FineVision optic, the double C-loop haptic design, and the hydrophobic GFree material.

WHAT THIS STUDY ADDS
- There were no statistically significant differences in visual acuity at far, near, and intermediate distances (under both photic and mesopic conditions) and contrast sensitivity between the POD F IOL and the POD F GF IOL.
- The POD F GF provided surgeons with an additional choice of hydrophobic material for trifocal IOLs, while maintaining good visual and refractive outcomes.
REFERENCES


OTHER CITED MATERIAL


Disclosures: None of the authors has a financial or proprietary interest in any material or method mentioned.

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