Rotational Stability of Monofocal and Trifocal Intraocular Toric Lenses With Identical Design and Material but Different Surface Treatment

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ABSTRACT

PURPOSE: To compare the rotational stability, total misalignment, and visual and refractive outcomes achieved with a trifocal toric versus a monofocal toric intraocular lens (IOL).

METHODS: In this prospective, interventional case series, eyes of patients consecutively scheduled for cataract surgery who had clinically relevant astigmatism were implanted with a FineVision Pod FT trifocal toric IOL or an Ankoris monofocal toric IOL (both PhysIOL SA, Liège, Belgium). Certain comorbidities, such as pseudoexfoliation syndrome, were allowed. IOL rotation and total misalignment were analyzed 15 minutes, 1 day, 1 week, 6 weeks, 6 months, and 1 year postoperatively.

RESULTS: Seventy-one eyes of 53 patients were assessed: 37 eyes were implanted with the trifocal IOL and 34 eyes with the monofocal IOL. More IOL rotation occurred in the monofocal group compared to the trifocal group (mean 4.23° ± 4.64° vs 2.55° ± 2.62°; P = .043, 12 months). Mean total misalignment was higher in the monofocal group (6.67° ± 6.59° at 12 months vs 3.79° ± 3.59° in the trifocal group) (P = .017). Postoperatively, more eyes achieved a refractive cylinder of 0.50 diopters or below in the trifocal group (65% at 12 months) than in the monofocal group, even in the monofocal subgroup analysis that excluded keratoconic eyes (42% at 12 months; P = .009).

CONCLUSIONS: The monofocal and trifocal toric IOLs both appear to effectively reduce refractive astigmatism and provide good visual acuity in astigmatic patients having cataract surgery. The trifocal toric IOL offers better rotational stability than the monofocal IOL, probably due to the higher frictional coefficient of its surface.

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Approximately 30% of patients undergoing cataract surgery have preoperative corneal astigmatism of 1.00 diopters (D) or higher.[1,2] The presence of astigmatism compromises postoperative visual acuity, particularly when multifocal intraocular lenses (IOLs) are implanted, thus making the correction of astigmatism exceeding 1.00 D at the time of cataract surgery[3-6] crucial for meeting patient expectations of spectacle independence. Many methods exist for reducing preoperative corneal astigmatism during cataract surgery, including toric IOL implantation. Clinical studies have shown toric lenses are safe and effective in astigmatic patients having cataract surgery,[7-9] but just 10° of toric IOL misalignment can reduce astigmatic correction by roughly one-third and 30° of misalignment can result in no astigmatic correction.[10-12]

This study evaluated the long-term rotational stability, total misalignment, and visual outcomes associated with implantation of a new monofocal and trifocal toric IOL platform (Ankoris and FineVision toric; PhysIOL SA, Liège, Belgium) for the correction of preexisting corneal astigmatism during cataract surgery. Both IOLs consist of the same material and share an identical design, except for lens surface. This is the first large study on the rotational stability of this IOL platform.

PATIENTS AND METHODS

Study Design and Patients

This prospective interventional case series was performed at Vista Alpina Eye Clinic in Visp, Switzerland. The study was performed in accordance with the tenets of the Declaration of

From Vista Alpina Eye Clinic, Visp, Switzerland.

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Helsinki and approved by the local ethics committee. All patients provided written informed consent.

Inclusion criteria were cataracts and coexisting total corneal astigmatism greater than 1.00 D oblique or with-the-rule [WTR] or greater than 0.75 D against-the-rule [ATR]. The patient's desire to be independent of reading glasses and the absence or presence of the exclusion criteria below determined whether a monofocal (Ankoris) or trifocal (FineVision Toric, Pod FT) toric IOL was implanted. Exclusion criteria for the trifocal toric group were irregular astigmatism, amblyopia, corneal disease, macular disease, or any ophthalmic pathology that could negatively affect postoperative visual acuity or contrast vision.

Exclusion criteria for monofocal toric IOL implantation were severe ophthalmic pathology with a major impact on visual function, such as corneal scarring, glaucomatous visual field defects, advanced macular disease, and corneal astigmatism with a predominantly irregular component.

In contrast to many refractive cataract surgery clinical studies, the current study assessed a "real life" patient population.[13] Specifically, eyes with pseudoexfoliation syndrome or slight macular gliosis were enrolled in both groups. Pseudoexfoliation syndrome has been identified as a risk factor for IOL rotation. Other conditions (gliosis, amblyopia, and keratoconus) can affect visual acuity. Eyes with stable keratoconus or amblyopia were enrolled in the monofocal group alone.

IOLs

Figures A-B (available in the online version of this article) show the study IOLs. The Ankoris is a monofocal toric IOL consisting of hydrophilic acrylic material. The biconvex aspheric optic is aberration correcting (-0.11 µm). This lens has an optic body diameter of 6 mm, overall diameter of 11.4 mm, and haptics with a double C-loop design and 5° angulation. The FineVision Toric Pod FT is a trifocal toric IOL with the same material characteristics and dimensions as the Ankoris. It has +1.75 D addition for intermediate, +3.50 D for near vision, and an unpolished surface. It also has diffractive rings on its anterior surface. The Ankoris has a polished surface.

Preoperative Assessment

Preoperatively, all patients underwent full ophthalmic examination, including refraction and corrected distance visual acuity (CDVA). Optical biometry and corneal topography were performed using the Galilei G6 Lens Professional (Ziemer, Port, Switzerland). IOL spherical power was calculated using the SRK/T, Hoffer Q, Holladay I, or Haigis formula, depending on axial length and anterior chamber depth. IOL cylinder power and target IOL axis were calculated using the online Ankoris and FineVision Toric Calculator (PhysIOLtoric, Toric IOL Calculator, version 3.6.6; http://www.physioltoric.eu), based on total corneal (ray-traced) astigmatism. The main incision was planned on the steep corneal meridian in all cases, independent of the axis of astigmatism. A surgically induced astigmatism of 0.40 D was assumed to err on the side of undercorrection of the corneal astigmatism and avoid flipping the axis of astigmatism. Target refraction was emmetropia in the trifocal group. In the monofocal group, emmetropia was targeted in 28 of the 34 eyes. The goal for three eyes with keratoconus was partial correction (two-thirds) of preexisting corneal astigmatism. In three other eyes, the target refraction was myopia.

To account for differences in preexisting ocular comorbidities and targeted refraction, two monofocal toric IOL subgroups were defined and used for comparisons with the trifocal toric IOL group. Monofocal subgroup 1 (for comparison of uncorrected distance visual acuity [UDVA]) excluded amblyopic eyes and keratoconic eyes with intended postoperative myopia. Monofocal subgroup 2 (for comparison of postoperative refractive cylinder) excluded three keratoconic eyes, given the residual cylinder in studies including keratoconic eyes was mostly higher than in those excluding them. All eyes in the trifocal and monofocal groups were available for rotational stability analysis.

Surgical Technique

An experienced surgeon (KV) performed all surgeries using a standard phacoemulsification technique with a 2.2-mm limbal incision on the steep corneal meridian. With the patient seated to prevent cyclotorsion, the target IOL axis was marked using a pendulum marker (ToMark corneal marker; Geuder, Heidelberg, Germany).[14]

A preloaded capsular tension ring (Morcher Easyring 14c, 11 mm; Morcher, Stuttgart, Germany) was injected into the capsular bag. A capsular tension ring was used in all cases to allow for more homogenous capsular shrinkage and therefore less decentration, rotation, and tilt postoperatively. The IOL was implanted using the Monarch C injector (Alcon Laboratories, Inc., Fort Worth, TX) after enlarging the main incision (maximal 2.3 mm) by re-entering the incision with the 2.2-mm clear cornea knife. After complete aspiration of viscoelastic anterior and posterior to the IOL, the IOL was aligned with the corneal markings. Clockwise and counterclockwise fine-tuning of the lens was permitted by the symmetrical shape of the IOLs (double C-loop haptics). Postoperative therapy consisted of tobramycin/dexamethasone and nepafenac.

Postoperative Assessment

Postoperative examinations were performed at 15 minutes, 1 day, 1 week, 6 weeks, 6 months, and 12 months. The actual IOL axis was assessed from images taken with the Galilei 6 frontal (black/white) camera, which also captures the Placido rings, showing the IOL axis marks, optic edge, haptics, and iris landmarks, as shown in **Figure CB**, available in the online version of this article). The images were imported into a Keynote file (version 6.6.1; Apple, Inc., Cupertino, CA) and rotational stability was analyzed according to a protocol modified after Maedel et al.[15]

Each frontal image was superimposed with a sketch of the IOL. The IOL sketch consisted of 0.25 pixel lines drawn in Keynote: two straight parallel lines touching the IOL axis marks on each side, and several easily recognizable IOL elements (optic and haptics edges, optic center, and the six round IOL axis marks [**Figure CA**]).

Each frontal image was magnified to match the size of the sketch (**Figure CC**). The position and axis of the IOL sketch were adjusted to the corresponding elements on the frontal image. To correct for head malpositioning and/or eye cyclotorsion during image recording, two to three peripheral iris landmarks were used as reference points throughout all study visits. All frontal images were assessed twice. In case of discrepancy (> 1°) between the two assessments, the frontal image was analyzed a third time and this result was used.

Absolute misalignment was defined as the difference between the target and actual IOL axis at any postoperative time. Rotation was defined as the difference in IOL axis at 15 minutes and any given postoperative time. Vector analysis was used for postoperative astigmatism analysis.[16]

Missing Data Handling and Statistical Analysis

For the primary study outcome (rotational stability and residual astigmatism), the last observation carried forward (LOCF) method was used for missing data resulting from missed visits or inability to perform an accurate measurement. The LOCF method was also used for one eye that underwent secondary surgery (IOL repositioning) to minimize bias, which would artificially favor rotational stability. The LOCF method was not used for the secondary study outcome (visual acuity).

Statistical analysis was performed using R software for statistical computing (Team RC. R: a Language and Environment for Statistical Computing). Normal distribution and homogeneity of variances were tested via Shapiro–Wilks and Bartlett's tests, respectively. If both tests were not significant, the *P* value of the *t* test was calculated, otherwise the non-parametric Wilcoxon signed rank test was used. A *P* value of less than .05 was considered statistically significant. All statistical tests were performed as two-sided tests, except for the comparison between the trifocal and monofocal group for lens rotation and total misalignment, where one-sided tests were used based on the assumption that these parameters are lower for the trifocal group, given the presumed higher frictional coefficient of its lens surface and preliminary clinical observations.

Correlation analysis was performed with Pearson's correlation coefficient for continuous variables or with the Wilcoxon signed-rank test for discrete variables. A longitudinal discrete mixed model (generalized estimating equation) was used to compare the percentage of eyes with a residual cylinder of 0.50 D or less.[17]

RESULTS

Fifty-three consecutive patients had monocular or binocular implantation of a monofocal (n = 34 eyes) or trifocal (n = 37 eyes) toric IOL. **Table 1** summarizes the preoperative demographic data for all study eyes. No differences were seen in the mean preoperative axial length and white-to-white distance of the monofocal and trifocal groups.

Although no difference was observed in the mean spherical IOL power of both groups, cylindrical IOL power was greater in the monofocal group (*P* = .008). Overall, 8.5% of all eyes had pseudoexfoliation syndrome (n = 6 eyes, 2 in the monofocal group, 4 in the trifocal group). There were 9 amblyopic eyes and 3 keratoconic eyes with reduced spectacle-corrected visual acuity in the monofocal group.

The LOCF method was used in 7 eyes for the analysis of rotational stability and residual astigmatism. The LOCF method was applied for missing data at a single visit (month 6 or 12) in 6 eyes and for all visits after week 1 in 1 eye. The latter eye underwent secondary surgery (IOL repositioning) after the week 1 study visit because of significant early rotation (16°) and misalignment (22°).

Visual Acuity

As shown in **Table A** (available in the online version of this article), UDVA in the trifocal group was comparable to UDVA in the monofocal subgroup 1 (excluding amblyopic eyes, keratoconic eyes, and eyes with intended myopia) at 6 weeks, 6 months, and 12 months.

Refractive Cylinder

As shown in **Table 2**, better refractive astigmatism outcomes were observed among the trifocal IOL group than in the overall monofocal or monofocal subgroup 2 (excluding the 3 keratoconic eyes) at all visits. The percentage of eyes with postoperative refractive astigma-

TABLE 1

Preoperative Patient Demographics According to Main IOL Groups and Monofocal IOL Subgroups

Parameter	Trifocal	Monofocal	P[a]	Monofocal Subgroup 1[b]	P[a]	Monofocal Subgroup 2[c]	P[a]
No. of patients	26	27	–	16	–	25	–
No. of eyes	37	34	–	19	–	31	–
Age, y (patients)							
Mean ± SD	63.3 ± 9.5	70.2 ± 10.3	.005[d,e]	73.1 ± 7.9	.006[d,e]	70.7 ± 10.6	.003[d,e]
Range	43 to 80	34 to 87	–	55 to 87	–	34 to 87	–
Sex							
Female	16	16	–	8	–	14	–
Male	10	11	–	8	–	11	–
Ocular comorbidity							
Pseudoexfoliation syndrome	4	2	–	1	–	2	–
Amblyopia	0	9	–	0	–	9	–
Keratoconus	0	3	–	0	–	0	–
Axial length (mm)							
Mean ± SD	23.95 ± 1.43	23.84 ± 1.31	.877[d]	23.52 ± 0.95	.955[d]	23.91 ± 1.35	.902[d]
Range	22.05 to 27.59	21.93 to 28.08	–	21.93 to 25.72	–	21.93 to 28.08	–
White-to-white (mm)							
Mean ± SD	11.98 ± 0.33	12.06 ± 0.38	.362[f]	12.07 ± 0.41	.384[f]	12.06 ± 0.40	.378[f]
Range	11.33 to 12.72	11.37 to 12.75	–	11.37 to 12.69	–	11.37 to 12.75	–
Total ray-traced astigmatism (D)							
Mean ± SD	1.86 ± 0.62	2.42 ± 1.08	.027[d,e]	2.04 ± 0.85	.941[d]	2.19 ± 0.77	.093[d]
Range	0.83 to 3.28	1.32 to 5.93	–	1.32 to 4.35	–	1.32 to 4.35	–
IOL sphere (D)							
Mean ± SD	19.01 ± 4.20	20.18 ± 3.73	.440[d]	20.92 ± 3.10	.634[d]	20.13 ± 3.87	.478[d]
Range	9.0 to 26.0	11.0 to 27.5	–	14.5 to 27.5	–	11.0 to 27.5	–
IOL cylinder (D)							
Mean ± SD	1.90 ± 0.88	2.51 ± 1.19	.008[d,e]	2.05 ± 0.90	.268[d]	2.25 ± 0.84	.038[d,e]
Range	1.00 to 3.75	1.50 to 6.00	–	1.50 to 5.25	–	1.50 to 5.25	–

IOL = intraocular lens; SD = standard deviation
[a]*Versus trifocal.*
[b]*Excluding amblyopic patients and patients with keratoconus or intended postoperative myopia.*
[c]*Excluding patients with keratoconus.*
[d]*Wilcoxon ranked-sum test.*
[e]*Statistically significant difference.*
[f]*t test.*

tism of 0.50 D or below fell over the 12-month follow-up period in all groups.

Figure D (available in the online version of this article) shows the preoperative corneal and 12-month postoperative refractive cylinder for the trifocal group and monofocal subgroup 2, via single-angle plots.[16] The preoperative corneal cylinder ranged between 0.83 and 3.28 D in the trifocal group and 1.32 and 4.35 D in the monofocal subgroup 2. All trifocal group eyes had a refractive cylinder of 1.00 D or below 12 months after surgery. At 12 months, 27 monofocal group eyes (87%; monofocal subgroup 2) had a refractive cylinder of 1.00 D or below.

IOL Rotation and Total Misalignment

As **Table B** (available in the online version of this article) and **Figure 1A** show, lens rotation and total misalignment worsened over time and total misalignment always exceeded lens rotation. Postoperative IOL

TABLE 2

Postoperative Refractive Cylinder and Percentage of Eyes With ≤ 0.50 D

Parameter	Total (Trifocal + Monofocal SG 2)	Trifocal	Monofocal	*P*[a]	Monofocal Subgroup 2	*P*[a]
Refractive cyl (D), 6 weeks (no.)	68	37	34	–	31	–
Mean ± SD	-0.40 ± 0.36	-0.32 ± 0.32	-0.60 ± 0.56	.017[b,c]	-0.48 ± 0.38	.063[b]
Range	-1.00 to 0.00	-1.00 to 0.00	-2.75 to 0.00		-1.00 to 0.00	
Refractive cyl (D), 6 months (no.)	68	37	34	–	31	–
Mean ± SD	-0.43 ± 0.38	-0.34 ± 0.32	-0.64 ± 0.57	.012[b,c]	-0.53 ± 0.42	.040[c,d]
Range	-1.25 to 0.00	-1.25 to 0.00	-2.50 to 0.00		-1.25 to 0.00	
Refractive cyl (D), 12 months (no.)	68	37	34	–	31	–
Mean ± SD	-0.52 ± 0.42	-0.41 ± 0.35	-0.72 ± 0.55	.007[b,c]	-0.66 ± 0.47	.017[b,c]
Range	-1.75 to 0.00	-1.00 to 0.00	-2.50 to 0.00		-1.75 to 0.00	
% cyl ≤ 0.50 D				.002[c,e]		.009[c,e]
6 weeks	70.6%	81.1%	52.9%	–	58.1%	–
6 months	67.6%	81.1%	47.1%	–	51.6%%	–
12 months	54.4%	64.9%	38.2%	–	41.9%	–

D = diopters; cyl = cylinder; SD = standard deviation
[a]*Versus trifocal.*
[b]*Wilcoxon ranked-sum test.*
[c]*Statistically significant difference.*
[d]*t test.*
[e]*Linear mixed generalized estimating equation models to analyze longitudinal profile.*

rotation was 3.35° ± 3.79° and total misalignment was 5.17° ± 5.40° after 12 months. One eye (monofocal IOL) required secondary surgery for IOL rotation. The impact of different IOL surfaces on rotation and total misalignment was analyzed by comparing the trifocal and monofocal groups (**Table B**). Mean IOL rotation and mean total misalignment were smaller in the trifocal than in the monofocal group at all postoperative visits (**Table B**, **Figures 1B-1D**).

Posterior Capsular Fibrosis

Capsular fibrosis requiring YAG capsulotomy at postoperative month 12 occurred at a similar rate (approximately 1 in 3 eyes) among the monofocal and trifocal groups.

Factors Influencing Rotational Stability

As shown in **Figure E** (available in the online version of this article), capsular fibrosis was the only variable that showed significant correlation with 12-month rotational stability (P = .011), with worse rotational stability seen among eyes scheduled for (or having undergone) laser capsulotomy.

DISCUSSION

The current study assessed the visual outcomes and rotational stability of a new trifocal and monofocal toric IOL platform. To our knowledge, this is the first study comparing rotational stability of two IOLs with identical design and material, but with a different surface treatment.

The mean UDVA of 0.13 and 0.14 logMAR (Snellen 20/27) seen in the current study for the trifocal group and monofocal subgroup 1, respectively, is comparable to that reported in other toric IOL studies. Alió et al.[18] reported a UDVA of 0.16 ± 0.15 logMAR (Snellen 20/28) 6 months after implantation of the monofocal AcrySof Toric IOL (Alcon Laboratories, Inc.) and Belluci et al.[19] observed a mean UDVA of 0.16 ± 0.22 logMAR (Snellen 20/28) 6 months after implantation of the first diffractive multifocal toric IOL (AT Lisa 909M; Carl Zeiss Meditec AG, Jena, Germany).

Excellent refractive results were also seen, with a refractive cylinder of 1.00 D or below in 94% of eyes and 0.50 D or below in more than half of the eyes (42% in the monofocal subgroup 2 and 65% in the trifocal group) at 12 months. This (clinically) small difference can be explained partly by the higher IOL rotation observed with the monofocal IOL and partly by the higher preoperative corneal astigmatism in the monofocal group.

Twelve-month postoperative IOL rotation and total misalignment outcomes compare favorably with those reported in the literature, despite including eyes with comorbidities such as pseudoexfoliation syndrome in the current study.[13,20] Although the two

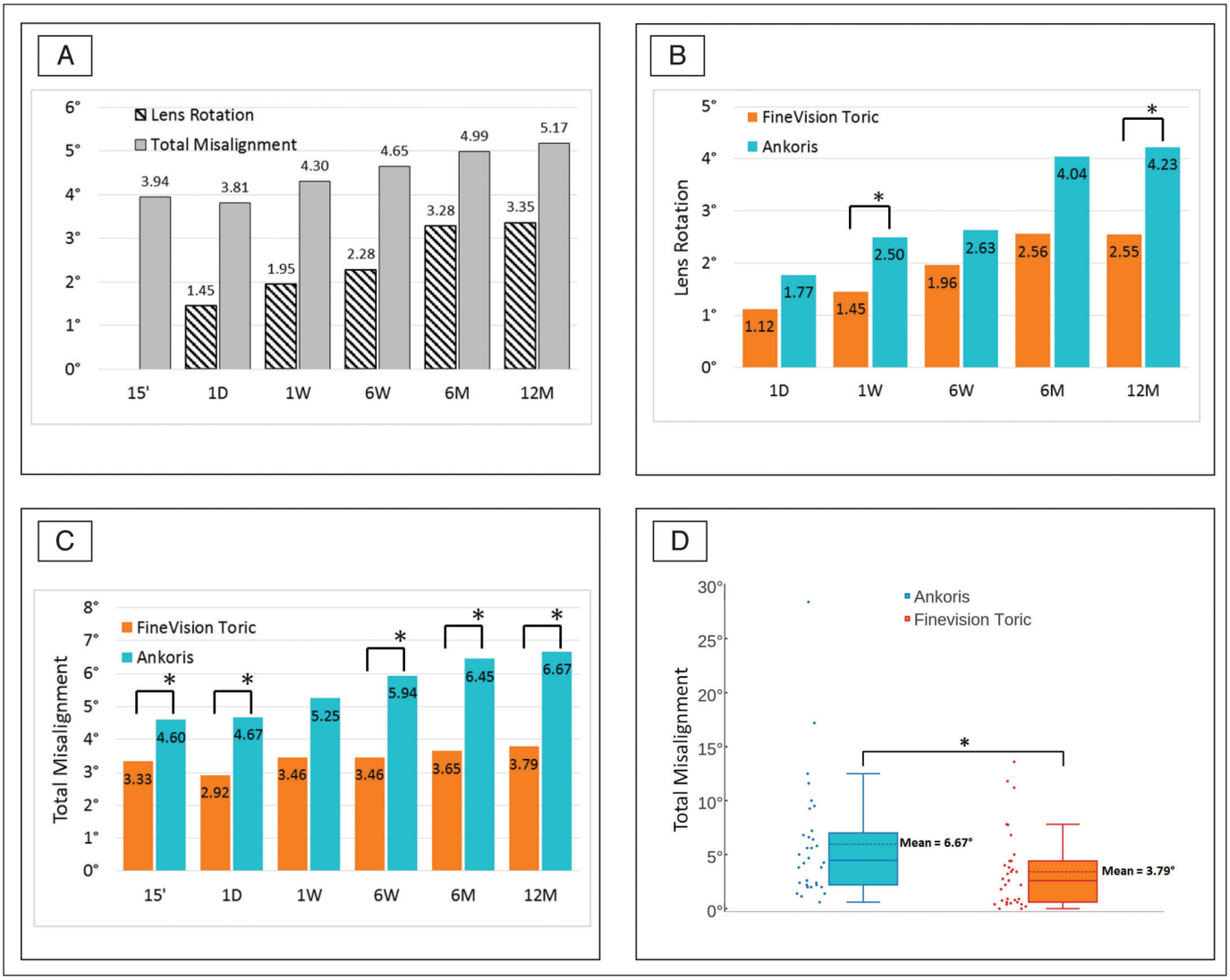

Figure 1. (A) Lens rotation and total misalignment for the total study group. (B) Lens rotation for the trifocal and monofocal groups (mean values). (*) $P < .05$. (C) Total misalignment for the trifocal and monofocal groups (mean values). (*) $P < .05$. (D) Total misalignment for the trifocal and monofocal groups, 12 months postoperatively. The rectangles represent the 25th and 75th percentiles. The thick lines represent the median values, the dashed lines the mean values. The whiskers represent the maximum and minimum values excluding outliers. The dots represent the individual date (eyes). (*) $P < .05$. The FineVision and Ankoris lenses are manufactured by PhysIOL SA, Liège, Belgium.

toric IOLs showed good long-term rotational stability overall, early misalignment reached 10° or more within 1 week in 6 eyes, with surgical repositioning needed in 1 eye.

Four methodological features allowed in-depth and robust analysis of rotational stability in the current study. First, outcomes were assessed over 12 months, with a total of six assessments of IOL alignment. Few studies have investigated the rotational stability of toric IOLs for up to 1 year after surgery.[20-23] Our data showed that, for this particular toric IOL platform, rotation mainly occurred in the first 6 months and then leveled off.

Second, a "real life" patient population including eyes with comorbidities that may affect IOL rotational stability or visual acuity, such as pseudoexfoliation syndrome or keratoconus, was used, unlike most other studies.[13]

Third, we accounted for the effect of head malpositioning and cyclorotation on the accuracy of the assessment of the IOL alignment. In a series of 500 measurements of toric IOL alignment, a mean difference of 1.0° ± 0.9° ($P = .02$) was observed between assessment with correction for cyclotorsion and head position versus uncorrected assessment; in 17% of measurements, the error reached 2° or more.[24]

Fourth, immediate postoperative IOL misalignment was captured by recording the IOL position 15 minutes after surgery, allowing "rotation" to be differentiated from "total misalignment," as defined in the method-

ology section. Although IOL rotation relates solely to IOL stability within the capsular bag, total misalignment from the intended axis arises from preoperative corneal marking error, inaccurate IOL alignment with the corneal markings intraoperatively, and rotation, starting within minutes after implantation.

Unsatisfactory IOL rotational stability has been discovered years after launch of new toric IOLs,[13,15,25] a scenario observed even with lenses that were strikingly similar but not identical in shape to existing toric IOLs with proven rotational stability.[15] A recent study revealed differing levels of rotational stability between IOLs with identical designs, but different materials.[26] The findings of the current study demonstrated better rotational stability and less total misalignment with the trifocal than the monofocal toric IOL despite an identical shape and IOL material. It is therefore likely that the difference in rotational stability is due to their differing surfaces. Lens surface adhesiveness is thought to be an important factor contributing to rotational stability, especially during the first few postoperative days, before capsular bag shrinkage occurs. We think that interaction between the IOL and capsular bag depends not only on IOL material,[27] but also on IOL surface treatment. The trifocal FineVision lens has an unpolished surface with anterior diffractive rings, whereas the monofocal Ankoris lens has a polished surface. Because rough surfaces produce greater friction, and the presence of friction inhibits rotation, the different surface may explain the difference in rotational stability and total misalignment.

Other factors, including incision integrity, residual viscoelastic, and intraocular pressure, may affect rotational stability. However, the current study went to great lengths to mitigate the influence of these confounders through surgical standardization.

The rotational stability of the three keratoconic eyes (12-month rotation: 1° to 3°, total misalignment 1° to 4°) was not different from the non-keratoconic eyes in the monofocal group. This finding is consistent with previous studies,[28] which have demonstrated similar rotational stability in keratoconic eyes compared to studies in eyes with regular astigmatism. Given the fact that the three keratoconic eyes exhibited reduced spectacle-corrected visual acuity and that we only aimed for partial correction (two-thirds) of corneal astigmatism in the three keratoconic eyes, they were not included in the analysis of visual acuity (monofocal subgroup 1) and residual cylinder (monofocal subgroup 2).

The main limitation of the current study is its small size (71 eyes), especially regarding the comparison between the monofocal and trifocal groups. However, because the findings consistently show a significantly different rotational stability of the two IOLs over 12 months, it appears that the current study results are noteworthy. Further clinical studies and in vitro research are required to build on the findings made in the current study.

This prospective interventional case series assessing the trifocal FineVision IOL and the monofocal Ankoris IOL showed that both toric IOLs provide good visual acuity and rotational stability in astigmatic patients having cataract surgery. The trifocal toric IOL offers better rotational stability and less total misalignment than the monofocal toric IOL, which may be due to the different frictional coefficient of its lens surface. Further research is required to determine the impact of the lens surface treatment on rotational stability.

AUTHOR CONTRIBUTIONS

Study concept and design (KV); data collection (KV); analysis and interpretation of data (KV); writing the manuscript (KV); critical revision of the manuscript (KV)

REFERENCES

1. Hoffmann PC, Hütz WW. Analysis of biometry and prevalence data for corneal astigmatism in 23,239 eyes. *J Cataract Refract Surg.* 2010;36:1479-1485.
2. Khan MI, Muhtaseb M. Prevalence of corneal astigmatism in patients having routine cataract surgery at a teaching hospital in the United Kingdom. *J Cataract Refract Surg.* 2011;37:1751-1755.
3. Hayashi K, Manabe S-I, Yoshida M, Hayashi H. Effect of astigmatism on visual acuity in eyes with a diffractive multifocal intraocular lens. *J Cataract Refract Surg.* 2010;36:1323-1329.
4. Villegas EA, Alcón E, Artal P. Minimum amount of astigmatism that should be corrected. *J Cataract Refract Surg.* 2014;40:13-19.
5. Wolffsohn JS, Bhogal G, Shah S. Astigmatism and vision: should all astigmatism always be corrected? *Br J Ophthalmol.* 2014;98:2-3.
6. Wolffsohn JS, Bhogal G, Shah S. Effect of uncorrected astigmatism on vision. *J Cataract Refract Surg.* 2011;37:454-460.
7. Mendicute J, Irigoyen C, Ruiz M, Illarramendi I, Ferrer-Blasco T, Montés-Micó R. Toric intraocular lens versus opposite clear corneal incisions to correct astigmatism in eyes having cataract surgery. *J Cataract Refract Surg.* 2009;35:451-458.
8. Lam DKT, Chow VW, Ye C, Ng PKF, Wang Z, Jhanji V. Comparative evaluation of aspheric toric intraocular lens implantation and limbal relaxing incisions in eyes with cataracts and ≤3 dioptres of astigmatism. *Br J Ophthalmol.* 2016;100:258-262.
9. Mingo-Botín D, Muñoz-Negrete FJ, Kim HRW, Morcillo-Laiz R, Rebolleda G, Oblanca N. Comparison of toric intraocular lenses and peripheral corneal relaxing incisions to treat astigmatism during cataract surgery. *J Cataract Refract Surg.* 2010;36:1700-1708.
10. Jin H, Limberger I-J, Ehmer A, Guo H, Auffarth GU. Impact of axis misalignment of toric intraocular lenses on refractive outcomes after cataract surgery. *J Cataract Refract Surg.* 2010;36:2061-2072.
11. Viestenz A, Seitz B, Langenbucher A. Evaluating the eye's ro-

tational stability during standard photography: effect on determining the axial orientation of toric intraocular lenses. *J Cataract Refract Surg.* 2005;31:557-561.

12. Shimizu K, Misawa A, Suzuki Y. Toric intraocular lenses: correcting astigmatism while controlling axis shift. *J Cataract Refract Surg.* 1994;20:523-526.
13. Visser N, Bauer NJC, Nuijts RMMA. Toric intraocular lenses: Historical overview, patient selection, IOL calculation, surgical techniques, clinical outcomes, and complications. *J Cataract Refract Surg.* 2013;39:624-637.
14. Popp N, Hirnschall N, Maedel S, Findl O. Evaluation of 4 corneal astigmatic marking methods. *J Cataract Refract Surg.* 2012;38:2094-2099.
15. Maedel S, Hirnschall N, Chen YA, Findl O. Rotational performance and corneal astigmatism correction during cataract surgery: aspheric toric intraocular lens versus aspheric nontoric intraocular lens with opposite clear corneal incision. *J Cataract Refract Surg.* 2014;40:1355-1362.
16. Holladay JT, Moran JR, Kezirian GM. Analysis of aggregate surgically induced refractive change, prediction error, and intraocular astigmatism. *J Cataract Refract Surg.* 2001;27:61-79.
17. Molenberghs G, Verbeke G. *Linear Mixed Models for Longitudinal Data.* New York: Springer; 2000.
18. Alió JL, Piñero DP, Tomás J, Alesón A. Vector analysis of astigmatic changes after cataract surgery with toric intraocular lens implantation. *J Cataract Refract Surg.* 2011;37:1038-1049.
19. Bellucci R, Bauer NJC, Daya SM, et al. Visual acuity and refraction with a diffractive multifocal toric intraocular lens. *J Cataract Refract Surg.* 2013;39:1507-1518.
20. Ninomiya Y, Minami K, Miyata K, et al. Toric intraocular lenses in eyes with with-the-rule, against-the-rule, and oblique astigmatism: one-year results. *J Cataract Refract Surg.* 2016;42:1431-1440.
21. Miyake T, Kamiya K, Amano R, Iida Y, Tsunehiro S, Shimizu K. Long-term clinical outcomes of toric intraocular lens implantation in cataract cases with preexisting astigmatism. *J Cataract Refract Surg.* 2014;40:1654-1660.
22. Kwartz J, Edwards K. Evaluation of the long-term rotational stability of single-piece, acrylic intraocular lenses. *Br J Ophthalmol.* 2010;94:1003-1006.
23. Holland E, Lane S, Horn JD, Ernest P, Arleo R, Miller KM. The AcrySof Toric intraocular lens in subjects with cataracts and corneal astigmatism: a randomized, subject-masked, parallel-group, 1-year study. *Ophthalmology.* 2010;117:2104-2111.
24. Vandekerckhove K. Evaluation of the rotational stability of toric IOL: importance of head positioning and cyclotorsion. Presented at the ESCRS Symposium on Cataract and Refractive Surgery; Copenhagen, Denmark; September 10-14, 2016.
25. Leyland M, Zinicola E, Bloom P, Lee N. Prospective evaluation of a plate haptic toric intraocular lens. *Eye (Lond).* 2001;15:202-205.
26. Draschl P, Hirnschall N, Luft N, et al. Rotational stability of 2 intraocular lenses with an identical design and different materials. *J Cataract Refract Surg.* 2017:43:234-238.
27. Linnola RJ, Werner L, Pandey SK, Escobar-Gomez M, Znoiko SL, Apple DJ. Adhesion of fibronectin, vitronectin, laminin, and collagen type IV to intraocular lens materials in pseudophakic human autopsy eyes: Part 2. Explanted intraocular lenses. *J Cataract Refract Surg.* 2000;26:1807-1818.
28. Nanavaty MA, Lake DB, Daya SM. Outcomes of pseudophakic toric intraocular lens implantation in keratoconic eyes with cataract. *J Refract Surg.* 2012;28:884–889.

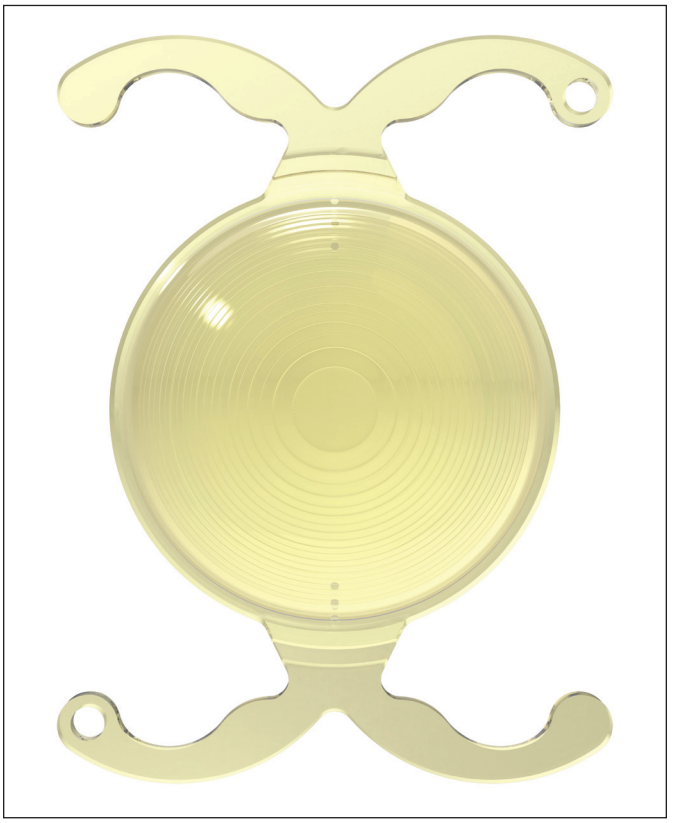

Figure A. Image of the trifocal toric intraocular lens (FineVision Toric Pod FT; PhysIOL, Liège, Belgium).

Figure B. Image of the monofocal toric intraocular lens (Ankoris; PhysIOL, Liège, Belgium).

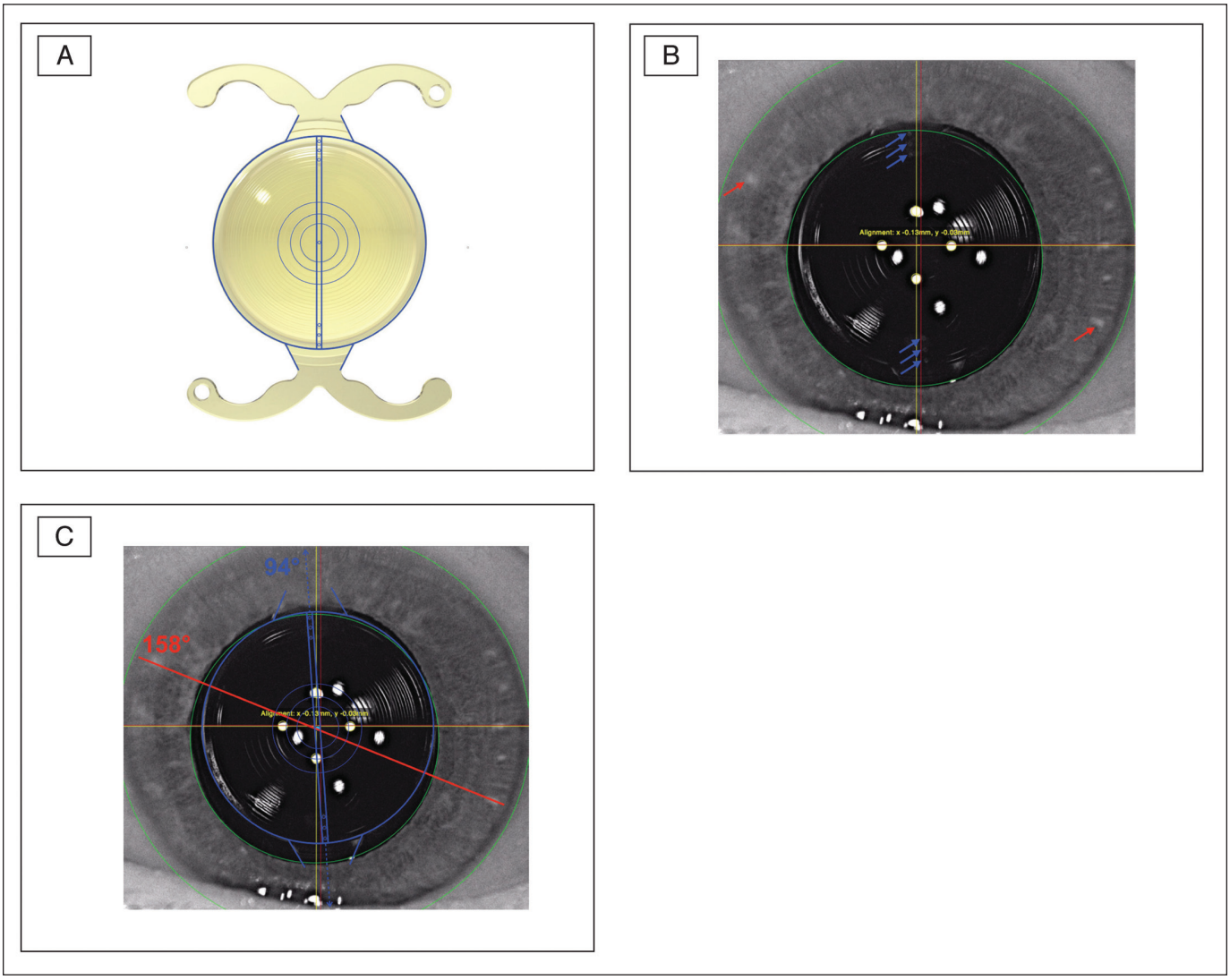

Figure C. (A) Image of the trifocal toric intraocular lens (IOL) with overlying sketch used to evaluate rotational stability. (B) Postoperative frontal image (Galilei 6 Lens Professional; Ziemer, Port, Switzerland). Blue arrows indicate IOL axis marks, red arrows indicate investigator-defined iris landmarks. (C) Postoperative frontal image (Galilei 6), superimposed with IOL sketch after adjusting position and angle.

TABLE A

Postoperative UDVA (logMAR)

Group	Trifocal	Monofocal	*P*[a]	Monofocal Subgroup 1	*P*[a]
6 weeks (no.)	37	31	–	18	–
Mean ± SD	0.11 ± 0.10	0.22 ± 0.17	.009[b,c]	0.14 ± 0.12	.676[d]
Range	-0.08 to 0.30	0.00 to 0.70	–	0.00 to 0.40	–
6 months (no.)	35	31	–	17	–
Mean ± SD	0.12 ± 0.08	0.22 ± 0.17	.008[b,c]	0.12 ± 0.10	.779[b]
Range	0.00 to 0.40	0.00 to 0.70	–	0.00 to 0.30	–
12 months (no.)	35	30	–	18	–
Mean ± SD	0.13 ± 0.09	0.23 ± 0.17	.009[b,c]	0.14 ± 0.10	.579[b]
Range	0.00 to 0.30	-0.08 to 0.70	–	-0.08 to 0.30	–

UDVA = uncorrected distance visual acuity; SD = standard deviation
[a]*Versus trifocal.*
[b]*Wilcoxon ranked-sum test.*
[c]*Statistically significant difference.*
[d]*t test.*

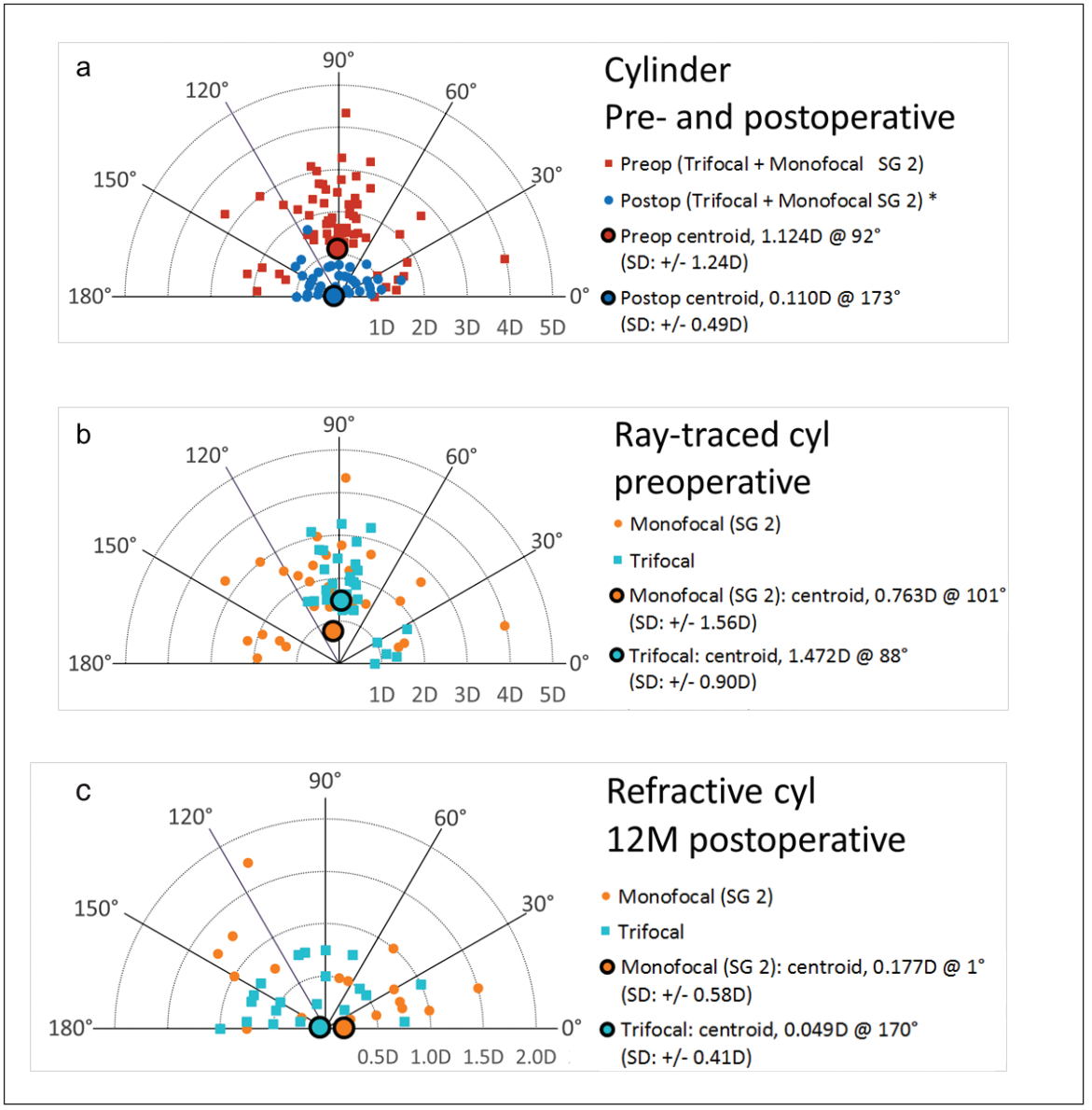

Figure D. (A) Single-angle polar plot of preoperative ray-traced corneal astigmatism and postoperative refractive astigmatism (total study group with the 3 keratoconic eyes excluded). Each circle represents 1.00 diopter (D) of cylinder (cyl). (B) Single-angle polar plot of preoperative ray-traced corneal astigmatism for the trifocal and monofocal (subgroup 2) groups. Each circle represents 1.00 D of cylinder. (C) Single-angle polar plot of postoperative refractive astigmatism for the trifocal and monofocal (subgroup 2) groups. Each circle represents 0.50 D of cylinder. (*) The central data points (0.00 D) are not visualized. In the trifocal and monofocal (subgroup 2) groups, 13 data points (35% of eyes) and 6 data points (19% of eyes) are at 0.00 D, respectively. SD = standard deviation

TABLE B

Postoperative Lens Rotation and Total Misalignment for Total Study Cohort and Trifocal and Monofocal Groups

	Lens Rotation (Degrees)				Total Misalignment (Degrees)			
Group	**Total Study Cohort**	**Trifocal**	**Monofocal**	***P*[a]**	**Total Study Cohort**	**Trifocal**	**Monofocal**	***P*[a]**
15 min (no.)	N/A	N/A	N/A	–	69	36	33	–
Mean ± SD	N/A	N/A	N/A	–	3.94 ± 3.19	3.33 ± 2.85	4.60 ± 3.44	.017[b,c]
Range	N/A	N/A	N/A	–	0.33 to 18.25	0.33 to 11.17	0.67 to 18.25	–
Day 1 (no.)	65	32	33	–	67	33	34	–
Mean ± SD	1.45 ± 2.03	1.12 ± 1.51	1.77 ± 2.41	.137[b]	3.81 ± 4.28	2.92 ± 2.76	4.67 ± 5.26	.037[b,c]
Range	0 to 11	0 to 7	0 to 11	–	0.08 to 29.25	0.08 to 11.17	0.33 to 29.25	–
Week 1 (no.)	66	35	31	–	68	36	32	–
Mean ± SD	1.95 ± 3.04	1.45 ± 2.18	2.50 ± 3.75	.049[b,c]	4.30 ± 5.18	3.46 ± 3.52	5.25 ± 6.50	.150[b]
Range	0 to 16	0 to 10	0 to 16	–	0.30 to 31.25	0.33 to 19.08	0.30 to 31.25	–
Week 6 (no.)	67	35	32	–	69	36	33	–
Mean ± SD	2.28 ± 3.08	1.96 ± 2.02	2.63 ± 3.93	.462[b]	4.65 ± 4.96	3.46 ± 3.27	5.94 ± 6.11	.008[b,c]
Range	0 to 16	0 to 8	0 to 16	–	0.33 to 28.75	0.40 to 12.17	0.33 to 28.75	–
Month 6 (no.)	68	35	33	–	71	37	34	–
Mean ± SD	3.28 ± 3.73	2.56 ± 2.22	4.04 ± 4.77	.266[b]	4.99 ± 5.29	3.65 ± 3.56	6.45 ± 6.43	.023[b,c]
Range	0 to 17	0 to 8	0 to 17	–	0.00 to 28.25	0.00 to 13.08	0.03 to 28.25	–
Month 12 (no.)	69	36	33	–	71	37	34	–
Mean ± SD	3.35 ± 3.79	2.55 ± 2.62	4.23 ± 4.64	.043[b,c]	5.17 ± 5.40	3.79 ± 3.59	6.67 ± 6.59	.017[b,c]
Range	0 to 18	0 to 10	0 to 18	–	0.00 to 28.75	0.00 to 12.58	0.33 to 28.75	–

N/A = not applicable; SD = standard deviation
[a]*Trifocal versus monofocal.*
[b]*Wilcoxon ranked-sum test (one-sided).*
[c]*Statistically significant difference.*

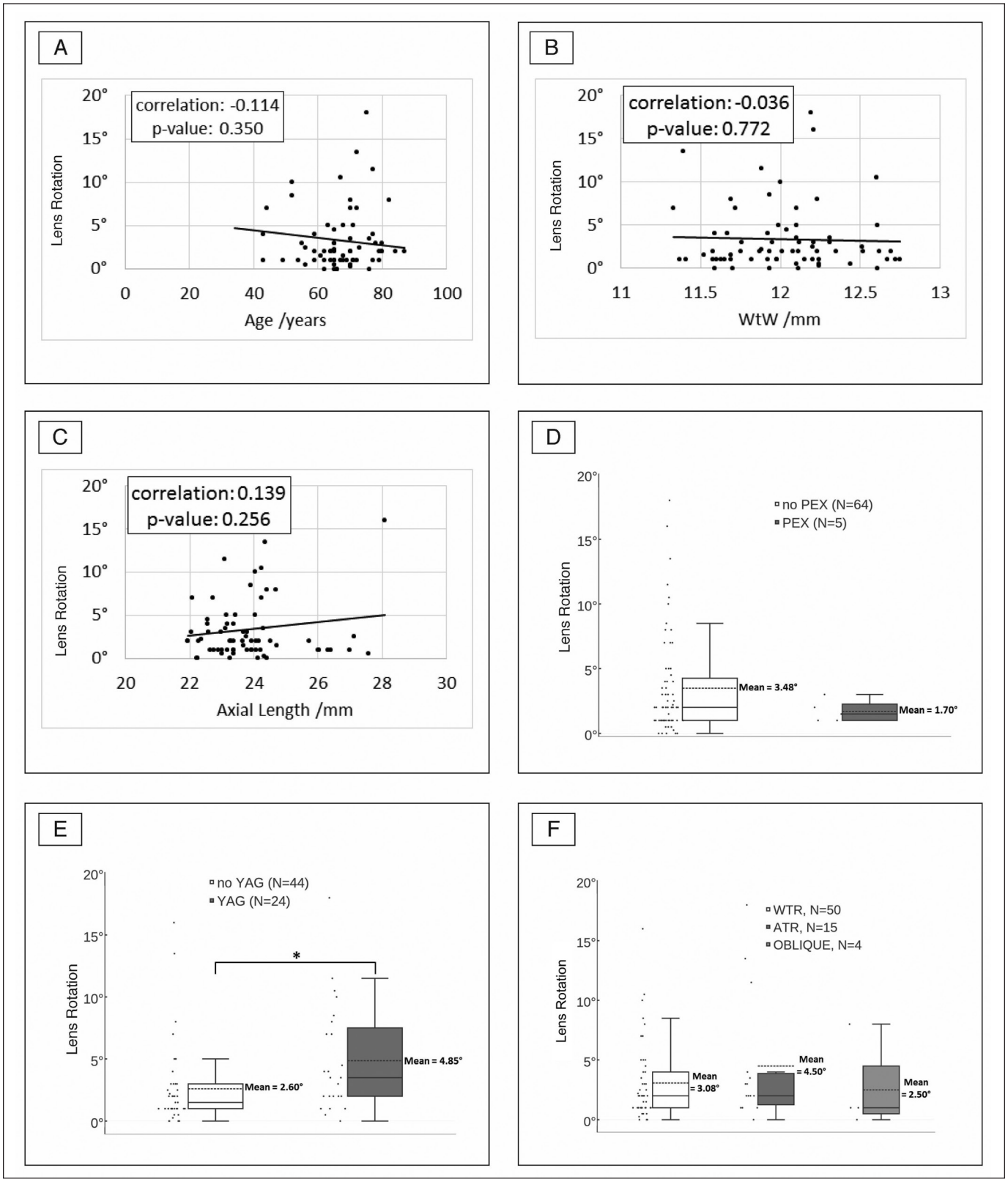

Figure E. Lens rotation (12 months postoperatively) in relation to: (A) age, (B) white-to-white distance (WtW), (C) axial length, (D) presence of pseudoexfoliation syndrome (PEX), (E) occurrence of capsular fibrosis, and (F) intraocular lens orientation. (*) $P < .05$. WTR = with-the-rule astigmatism; ATR = against-the-rule astigmatism