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The Effects of Axis-flip of the Refractive Cylinder on vision and patient reported outcome measures following Toric Intraocular Lens implantation

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Abstract

Purpose: To investigate the effects of cylinder axis-flip following toric intraocular lens (TIOL) implantation on vision and patient reported outcome measures (PROMs).

Setting: Teaching hospital in the United Kingdom.

Design: Post-hoc analysis of data from patients who participated in a prospective randomised study of TIOLs.

Methods: Axis-flip was defined as a change in post-operative refractive cylinder axis of $90^{\circ} \pm 22.5^{\circ}$ from the pre-operative biometric axis. Uncorrected distance visual acuity (UDVA), best-corrected distance visual acuity (BDVA), residual refractive cylinder (RC), and CATPROM-5 and EQ5D3L quality of life (QOL) scores were analysed.

Results: At 6 months, axis flip occurred in 29 (34.5%) of 84 eyes, of which 28 had with-the-rule astigmatism (WTR) pre-operatively. Mean (\pm standard deviation) UDVA (logMAR) was 0.13 (0.16) in flipped cases (FC) and 0.10 (0.14) in un-flipped cases (UF) ($p=0.88$). BDVA was 0.01 (0.11) in FC and was 0.00 (0.09) in UF ($p=0.68$). Mean RC was 0.74 dioptres (D) (0.41) in FC and 0.93D (0.47) in UF ($p=0.08$). Mean CATPROM-5 score was -6.22.98 (2.56) in FC and -5.52 (3.03) in UF ($p=0.29$). Mean EQ5D3L calibrated score was 0.89 (0.19) in FC and 0.85 (0.19) in UF ($p=0.35$). Retrospectively applying coefficients of adjustment to account for posterior corneal astigmatism (PCA), suggested that 6 eyes (21%) of FC with WTR might have avoided axis-flip.

Conclusions: Axis flipping following TIOL implantation did not adversely influence visual acuity or PROMs scores. Most FC had WTR pre-operatively. Adjusting for PCA might have reduced axis flip in some of these eyes.

Introduction

Post-operative residual corneal astigmatism following cataract surgery (CS) is a contributory factor to suboptimal uncorrected distance visual acuity (UDVA), with one study showing a 0.16 logMAR reduction in UDVA for every 1.00D of residual cylinder post CS¹. An effective method of correcting corneal astigmatism is the implantation of toric intraocular lenses (TIOLs)²⁻⁴. TIOLs have been shown to achieve superior UDVA and greater rates of spectacle independence compared to non-toric monofocal intraocular lenses, limbal relaxing incisions (LRIs) and opposite clear corneal incisions (OCCIs)²⁻⁴.

TIOL spherical and cylindrical powers are typically selected from online calculators provided by lens manufacturers. The decision to under-correct or over-correct astigmatism, thereby 'flipping' the astigmatic cylindrical axis is somewhat ambiguous⁵. Traditionally, it has been suggested that a patient's baseline cylindrical axis should not be flipped as this might lead to poor tolerance and a lower quality of vision⁶. As such, cataract surgeons may opt to under-correct a patient's astigmatism to avoid axis flipping, especially in cases of with-the-rule (WTR) astigmatism⁶. Such opinions may derive from optometric practice where overcorrection and axis flipping in spectacles can result in visual disturbances from meridional magnification. This does not apply with TIOLs, where the IOL correction occurs near to the nodal point of the eye⁷⁻⁸.

At present, there is limited data in the literature assessing the tolerance and adaptations of patients to an axis-flip following CS and TIOL implantation. Hoffmann et al ⁷ in a series of 40 eyes undergoing TIOL implantation, reported 42.5% with astigmatic overcorrection and an axis-flip, with no reported cases of intolerance. More recently, in a retrospective study of 206 eyes, Beheregaray et al ⁸ suggested that axis-flip to WTR astigmatism might be beneficial to provide greater rates of long-term spectacle independence and better UDVAs, due to the general age-related drift to against-the-rule (ATR) astigmatism ⁸.

To further investigate the relevance of flipping of the astigmatic axis with TIOL implantation, we undertook this current study, performing a post-hoc analysis on data from a randomised control trial of TIOLs ⁹, with the aim of investigating the effects of axis-flip on post-CS visual performance and patient reported outcome measures (PROMs). To analyse the importance of coefficients of adjustment for posterior corneal astigmatism (PCA) in the calculation of TIOL powers and possible axis-flip, we recalculated the recommended TIOL powers for each eye with the inclusion of the PCA coefficients, which were not available at the time of commencement of our study, and compared any new TIOL powers those originally calculated to identify cases where axis flipping might not have occurred with PCA inclusion.

Methodology

This was a post-hoc analysis on data from a prospective, randomised, case-control study undertaken at Guy's and St.Thomas' Hospital, NHS Foundation Trust (clinicaltrial.gov data base number NCT04122651). Health Research Authority ethics approval (19/WA/0272) was obtained for the study, which adhered to the tenets of the Declaration of Helsinki and the UK Data Protection Act (2018). Informed consent was gained from each patient as part of the original study, including consent for analysis of the original data for further studies.

The inclusion criteria included patients over the age of 18 years with symptomatic cataracts and regular anterior corneal astigmatism of 1.50 dioptre cylinder (DC) or above on the IOL Master 700 biometer's (Carl Zeiss Meditec, AG, Germany) anterior keratometry function. Astigmatism regularity was confirmed by Scheimpflug tomography (Oculus Inc., Arlington, VA, USA). Exclusion criteria consisted of any visually impairing co-morbidities including amblyopia, previous ocular surgery, corneal scarring, glaucoma, retinal pathology causing visual impairment, or any ocular or neurological condition affecting vision. Patients with corneal astigmatism of over 5.00DC were excluded.

In the original study⁹, the first operated eye of each patient was randomised to either the control group (CG) or the intervention group (IG) using a shuffled envelope system performed by non-clinical members of staff not involved in the running of the study. It was not possible to mask the surgical team to the treatment arm, but all other personnel involved in the study including patients were masked. The refractive target for all subjects was emmetropia, with the aim of fully correcting the baseline corneal astigmatism with selection of the TIOL with the lowest residual cylinder. All patients in the study received the Rayner aspheric RayOne single-piece, hydrophilic acrylic TIOL RAO610T (Rayner, Worthing, West Sussex, UK).

Prior to surgery, calculation of TIOL power was undertaken by inputting axial length, anterior chamber depth and keratometry readings from the IOL Master 700 (Carl Zeiss Meditec, AG, Germany) into the online Raytrace Premium calculator (Rayner Ltd, Worthing, UK), with a surgically induced astigmatism (SIA) estimate of 0.25D with a 2.4 millimetre (mm) main wound incision for each case based on previously published studies¹⁰⁻¹¹. This calculator predicts possible residual cylindrical correction after TIOL insertion for

varying TIOL choices with a negative cylinder indicating under correction (the cylinder axis remains un-flipped), and a positive post-operative residual cylinder indicating overcorrection and an axis-flip. The calculator does not document the predicted post-operative astigmatic axis, which is an available feature on some other manufacturers' online TIOL calculators. The posterior corneal astigmatism (PCA) option was not utilised, as this function was not available within the online calculator at the time of study commencement.

Patients in the CG received a TIOL calculated to achieve full correction of the corneal astigmatism. Patients in the IG subjects received either a 2.00DC or 4.00DC TIOL, with residual corneal astigmatism corrected by OCCI where required. The amount of astigmatism corrected by OCCI was estimated to be 0.25D, when using a 2.40mm keratome and 0.50D when using a 2.75mm keratome, permitting up to 1.00D of correction¹⁰⁻¹¹. The choice of 2.00DC or 4.00DC TIOLs was based on the patient's baseline biometric astigmatism. For example, a patient with astigmatism of 2.50DC would receive a 2.00DC cylinder TIOL along with an on-axis OCCI using 2.40mm keratome to induce a further 0.25D of correction (in addition to the 0.25D induced by the on-axis main wound incision). Where a total of 1.00DC of additional astigmatism correction was required, the main wound was enlarged using a 2.75mm keratome, and this was coupled with an OCCI using the 2.75mm keratome. In cases where an astigmatic overcorrection was calculated pre-operatively, off-axis (perpendicular to the TIOL cylinder axis) incisions were used to offset this. The total estimated surgically corrected astigmatism delivered via the main corneal wound (and any required OCCI) was applied as the SIA into the Raytrace software. In both the CG and the IG, the TIOL with the lowest residual astigmatism was selected in order to aim for the most optimal UDVA.

Patients were reviewed within two weeks (to check rotational stability of the TIOL) as part of standard care, and then at 4 weeks (4W) and 6 months (6M) post-operatively. Patients were reviewed by their community optometrist after their 4W visit (or following CS of their second eye where needed). The stability of the TIOL was reviewed using the scale on the vertical arm of the slit lamp following pupil dilatation. Primary outcome measures in the original study were post-operative monocular uncorrected distance visual acuity (UDVA) and best-corrected distance visual acuity (BDVA) in logMAR, and residual subjective refractive cylinder (RC). Secondary outcome measures included patient-reported outcome measures (PROMs) including CATPROM-5¹² and EuroQoL EQ-5D-3L questionnaire scores¹³, TIOL rotational stability, and adverse events. Vectoral analysis was performed using the Alpins vector method¹⁴.

Post-hoc Analysis

6M follow-up data was analysed to look at the number of cases of axis-flip from the baseline corneal astigmatism on the IOL Master 700 (Carl Zeiss Meditec, AG, Germany) in all cases. Our definition of axis-flip was a change in axis of 90 +/- 22.5 degrees from baseline, where the post-operative subjective refractive positive cylinder was compared to the baseline biometric steep axis. Baseline refraction was not utilised due to the presence of dense age-related cataracts, which limited their reliability. To categorise the type of astigmatism pre- and post-operatively, we defined with-the-rule astigmatism (WTR) to be when the steep meridian axis falls between 90 +/- 30 degrees, against-the-rule astigmatism (ATR) between 0-30 and 150-180 degrees, and oblique astigmatism (OB) between 31 to 59 degrees and 121 to 149 degrees¹⁵. CATPROM-5 and EuroQoL EQ-5D-3L scores are validated patient-completed questionnaires assessing the quality of vision and general health indicators pre- and post-cataract surgery¹²⁻¹³. As this was a post-hoc analysis, we were unable to undertake additional post-operative examinations to construct

defocus curves and objectively measure the level of tolerance to the post-operative astigmatism. The 6M CATPROM-5 measure the quality of vision pre- and post-CS and the patient reported calibrated scores were therefore used as a proxy measure of patient tolerance to their post-operative cylinder axis.

To investigate the role of PCA inclusion in TIOL calculation with regards to axis flip, we retrospectively applied the PCA coefficient of adjustment function for each eye and analysed any differences in the new selected TIOL power compared to the original TIOL implanted, any differences in residual astigmatism, and to identify cases where axis flipping might not have occurred with PCA inclusion. The PCA was added to the Raytrace calculator by the manufacturers to improve accuracy, with a study on 715 eyes showing a mean PCA of 0.3D ¹⁶.

Statistical analysis

Statistical analysis was performed using GraphPad Prism version 8.0.0 for Mac (GraphPad Software, San Diego, California USA). Alpins' vector analysis was performed using the online VekTrAK software (available at <http://www.assort.com>). Data set normality was assessed using the Shapiro-Wilk test. Differences between the two groups were analysed using Student's independent t-test for parametric data or its non-parametric equivalent where appropriate. The Rasch-calibrated CATPROM-5 scores were analysed using the Excel macros system provided by the CATPROM-5 developer ¹². The Pearson correlation coefficient was used to test for association between variables. Patient demographic data were compared using Fisher's exact test. Statistical significance set at $p < 0.05$

Results

One hundred and two patients were enrolled into the original study⁹ between October 2019 and March 2022. Nine did not undergo CS and were withdrawn. One did not meet the inclusion criteria, and one was removed from analysis following posterior capsular rupture as the patient did not receive a TIOL. Ninety-one patients attended 4W follow-up appointments and eighty-four patients attended 6M follow-up (43 in the IG and 41 in the CG).

At 6M follow-up, 29 (34.5%) of the 84 eyes of 84 patients had an axis-flip. Table 1 shows the pre-operative baseline demographic data for the group of flipped cases (FC) and the group of un-flipped (UF) cases. There were no demographic differences between FC and UF, except for less eyes with ATR and OB in the FC group ($p < 0.0001$).

At 6M the mean (+/- standard deviation) UDVA (logMAR) was 0.13 (0.16) in the FC and 0.13 (0.14) in the UF ($p = 0.88$) (table 2). The BDVA was 0.01 (0.11) in the FC group and was 0.00 (0.09) in the UF group ($p = 0.68$). The SE was comparable between the two groups ($p = 0.20$). The mean RC (DC) was 0.74 (0.41) in the FC group and 0.93 (0.47) in the UF group ($p = 0.08$). The mean CATPROM-5 score was -6.22 (2.56) in the FC group and was -5.52 (3.03) in the UF group ($p = 0.51$). The mean EQ5D3L Calibrated Score was 0.89 (0.19) in FC and 0.85 (0.19) in UF ($p = 0.35$). The mean EQ5D3L Raw Score was 84.97 (13.72) in FC and 88.72 (13.43) in UF ($p = 0.23$). The mean change in axis from the baseline biometric cylinder (degrees) at 6M was 79.62 (7.22) in the FC group and 30.93 (19.86) in the UF group ($p < 0.0001$). The proportion of WTR:ATR:OB astigmatism was 0:28:1 in the FC group, and 8:34:13 in the UF group ($p = 0.0025$). Within the FC group 28 eyes flipped from WTR to ATR, none flipped from ATR to WTR or OB, one flipped from OB

to OB based on our definition of axis-flip (table 2). There was no statistically significant difference in the mean post-operative axis change between the original CG (45.02°, SD 30.93) and the IG (50.59°, SD 25.96) ($p=0.40$).

Table 3 displays the vector analysis between the FC group and the UF group at 6-month follow-up. The target induced astigmatism (D) was 2.22 (0.58) in FC group and 2.33 (0.62) in the UF group ($p=0.43$). The surgically induced astigmatism (D) was 2.90 (0.76) in the FC group and 2.14 (0.94) in the UF group ($p=0.0003$). The difference vector was 0.74 (0.41) in the FC group and 0.93 (0.47) in the UF group ($p=0.08$). The angle of error (degrees) was 1.39 (3.34) in the FC group and 4.91 (11.52) in the UF group ($p=0.15$). The magnitude of error (D) was 0.69 (0.36) in the FC group and -0.18 (0.59) in the UF group ($p<0.0001$). The correction index was 1.32 (0.17) in the FC group and 0.91 (0.28) in the UF group ($p<0.0001$).

Recalculation of TIOL powers with the inclusion of coefficients of adjustment for PCA showed a reduction in the recommended TIOL cylindrical powers from a mean (+/- standard deviation) of 2.59DC (0.81) with no PCA function to 2.04DC (0.67) with the PCA function ($p=0.01$) for FC with WTR preoperatively (table 4). For UF with ATR the recommended TIOL cylindrical powers increased from 2.45DC (0.72) with no PCA function to 2.86DC (0.81) with the PCA function ($p=0.05$). There were six eyes (21%) of FC, all with WTR preoperatively, where the selected IOL power with the PCA function would have been reduced by at least 1DC. In all six cases, this reduction in TIOL power was at least 50% greater than the residual astigmatism present after axis flip, suggesting that these eyes might not have flipped if the PCA function had been used. Conversely, there were two eyes (4%) of UC, both with ATR, where the increase in TIOL power of 1DC using the

PCA function was at least 50% more than the residual astigmatism suggesting that these eyes could have flipped with these increased TIOL powers.

Discussion

In this post-hoc analysis of a randomised case-control study, we found approximately 1 in 3 patients (34.5%) had an axis-flip following TIOL implantation when aiming for full correction of the baseline corneal astigmatism. These results are comparable to those of Hoffmann et al ⁷. In their study, 42.5% of eyes had an axis-flip, with no reported cases of intolerance. Similarly, we found no differences in visual acuity or PROMs scores between our FC and UF groups (table 2). More specifically, the 6M CATPROM-5 score improved in 82/84 patients compared to the pre-operative baseline. In two patients, one in the FC (pre-operative -3.37 vs 6M -2.29) and one in the UF (-6.80 vs -4.92), the CATPROM-5 scores were slightly lower compared to pre-operative levels at 6M follow-up. However, despite these lower scores at 6M, both patients were happy with their post-operative vision with 6M UDVA 0.00logMAR and a residual cylinder of 0.25D in the FC patient, and an UDVA of 0.20logMAR and a residual cylinder of 0.50D in the UF patient. There was no reduction in the calibrated or raw EQ5D3L scores at 6M follow-up compared to pre-operative levels in either case.

As expected, the mean surgically induced astigmatism (SIA) was higher in the FC group, which showed an astigmatic overcorrection (table 2). Twenty-eight of 29 (97%) of our cases of axis-flip, had WTR pre-operatively and no cases with ATR flipped their axis in our study (table 2). The posterior corneal curvature (PCA) function on the online Raytrace Premium calculator (Rayner Ltd, Worthing, UK) was not utilised in our study to calculate the required power of the TIOL, as this function was not available at the time of study

commencement. PCA is steeper than the anterior surface curvature, typically producing a negative lens effect of -5 to -6 D. It generally has an astigmatic component, which is steeper vertically in over 70% of eyes and remains stable with age¹⁵. Given the negative lens effect of PCA, in most eyes, PCA will therefore reduce WTR and increase ATR. As such, not including it in TIOL calculation can result in over-correction of WTR and under-correction of ATR, especially with TIOL cylindrical calculations of 2.5 D or less^{15,17-18}.

Retrospectively recalculating the TIOL powers in our cohort, with coefficients of adjustment for PCA showed significant reductions in the recommended TIOL cylindrical powers in eyes with WTR and increases in TIOL powers in eyes with ATR (table 4) which is consistent with a study by Goggin et al¹⁵. Prospective studies with the inclusion of coefficients of adjustment for PCA are required to ascertain the degree to which PCA inclusion might reduce axis-flip in eyes with WTR and increase axis-flip in eyes with ATR. We identified six eyes (21%) of FC, all with selected TIOL powers reduced by 1.0DC or more and where the cylindrical power reduction was at least 50% greater than any residual astigmatism present after axis-flip, where it might be assumed that axis-flip might not have occurred with PCA inclusion. There were 2 eyes (4%) in the UC group with ATR, where the increase in TIOL power of 1.0DC using the PCA function was at least 50% more than the residual astigmatism, suggesting that these ATR eyes could have flipped. Given that none of our cases of axis-flip occurred in eyes with ATR, tolerance to axis flipping in eyes with ATR, both short and long term, merits further investigation, especially as most manufacturers online TIOL calculators now include coefficients of adjustments for PCA so more eyes with ATR might be expected to flip.

A retrospective study on 1535 patients by Hasegawa and colleagues found UDVA to be superior in eyes with less cylinder or WTR astigmatism compared to oblique and ATR astigmatism ¹⁹. Considering that most of our cases flipped from WTR to ATR, such findings might merit further investigation with regards to axis-flip, where ATR to WTR might be more acceptable than WTR to ATR, although we found no differences in vision between FC and UF (table 2). Studies also show that younger patients are more likely to have WTR astigmatism, with a drift towards ATR with age ²⁰⁻²². It is important to appreciate that the duration of the drift from WTR to ATR astigmatism with increasing age may also be variable in different populations and challenging to anticipate. In an interesting retrospective study by Oshika et al ²², the astigmatic-correcting power of TIOLs implanted in eyes with pre-operative ATR astigmatism declined 5 years after CS, with the authors suggesting that over-correction may need to be considered in cases of ATR to account for this. Hence, the age in which a patient undergoes CS and TIOL may be of relevance when deciding on whether to under/overcorrect a patient's baseline astigmatic cylinder to anticipate this age-related drift. The rationale for the age-related drift to ATR is remains unclear and prospective longitudinal studies on axis drift in patients undergoing TIOL may shed further light on this topic

We acknowledge the limitations in our study. As the study was conducted during the COVID-19 pandemic patient recruitment was challenging and it was not possible to achieve the initial recruitment target. However, the power of the study was still sufficient to detect clinically significant difference between the control group and intervention group in the original study. In our post-hoc analysis, we were unable to perform additional examinations and therefore construct defocus curves for our patients to formally assess astigmatic tolerance. Therefore, our proxy measure of tolerance was an improvement in

the 6M CATPROM-5 scores (which are patient-reported outcome measures of vision pre- and post-CS) compared to baseline and we acknowledge this limitation. CATPROM-5 scores were completed by patients in reference to their operated eye (rather than both eyes). We did not find a statistically significant difference between the FC and UF groups, with mean improvements in CATPROM-5 scores compared to the pre-operative baseline. We found one patient in the UF group and one in the FC group where the 6M CATPROM-5 scores were slightly lower than the pre-operative baseline.

In conclusion, one-third of our patients had an axis-flip following TIOL implantation, with the vast majority flipping from WTR to ATR. We did not find any evidence for intolerance to an axis-flip, with no differences in the mean CATPROM-5 scores, EQ5D3L scores, UDVA, BDVA, or residual subjective refractive cylinder scores between the flipped and un-flipped cases. As highlighted by Beheregaray et al ⁸, aiming for full correction of a patient's underlying corneal astigmatism when selecting a TIOL might allow patients to achieve better UDVA and reduce distance spectacle requirements, whereas under-correction of the cylinder (to avoid an axis-flip) might leave patients with potentially lower UDVA. In our cohort of patients with age-related visually symptomatic cataracts, it is possible that the post-operative improvement in the quality of vision may offset any potentially negative effects of axis-flip, and hence, aiming for full-correction will allow better UDVA, lower dependence on distance spectacles, and more satisfied patients. More studies are required to assess the long-term effects on axis-flip especially in eyes flipped to ATR given its increase with age, as well as in younger patients undergoing refractive lens exchange and in patients who with the inclusion of coefficients of adjustments for PCA might flip from ATR.

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Table Legends:

- Table 1: Baseline Demographics of the two study groups.

Parameter	Un-flipped Group (n=55) Mean (SD)	Flipped Group (n=29) Mean (SD)	p-value (95% Confidence Interval)
Age (Years)	70.04 (11.86)	68.62 (8.39)	0.57 (-3.52, 6.35)
Gender (Male:Female)	26:29	11:18	0.49
Pre-operative UDVA (logMAR)	0.95 (0.48)	0.83 (0.45)	0.29 (-0.33, 0.10)
Pre-operative BDVA (logMAR)	0.56 (0.45)	0.45 (0.37)	0.28 (-0.30, 0.09)
Pre-operative Biometric K1-K2 (D)	2.33 (0.62)	2.22 (0.58)	0.43 (-0.39, 0.17)
Pre-operative Pentacam K1-K2 (D)	2.27 (0.72)	2.12 (0.56)	0.35 (-0.45, 0.16)
Axial Length (mm)	24.50 (1.50)	24.44 (1.64)	0.87 (-0.77, 0.65)
CATPROM-5 Rasch-calibrated Score	0.81 (2.69)	0.31 (2.44)	0.40 (-1.70, 0.68)
EQ-5D-3L Value Score	0.87 (0.18)	0.82 (0.25)	0.34 (-0.14, 0.05)
EQ-5D-3L Raw Score	81.27 (19.04)	82.62 (17.12)	0.75 (-7.06, 9.75)
IG:CG (n)	27:28	16:13	0.19
WTR:ATR:O (n)	22:28:5	28:0:1	<0.0001

Table 1: Baseline Demographics of the two study groups.

SD=Standard deviation; UDVA=Uncorrected distance visual acuity; BDVA= Best-corrected distance visual acuity; K=Keratometry; D=Dioptres; WTR=With-the-rule; ATR=Against-the-rule; O=Oblique.

Fisher's exact test used to compare proportions of each gender between the two groups.

Chi-square test used to compare proportions of WTR, ATR and O astigmatism between the two groups.

Unpaired t-test used to compare means between two groups. Mean (+/-Standard deviation)

• Table 2: Post-operative Outcomes at 6-months follow-up.

Parameter	Flipped Group (n=29) Mean (SD)	Un-flipped Group (n=55) Mean (SD)	p-value (95% Confidence Interval)
UDVA (logMAR)	0.13 (0.16)	0.13 (0.14)	0.88 (-0.06, 0.07)
BDVA (logMAR)	0.01 (0.11)	0.00 (0.09)	0.68 (-0.05, 0.04)
SE (D)	-0.43 (0.52)	-0.29 (0.47)	0.20 (-0.37, 0.08)
Residual Refractive Cylinder (D)	0.74 (0.41)	0.93 (0.47)	0.08 (-0.02, 0.39)
CTPROM-5 Rasch-calibrated Score	-6.22 (2.56)	-5.52 (3.03)	0.29 (-2.01, 0.61)
EQ5D3L Calibrated Score	0.89 (0.19)	0.85 (0.19)	0.35 (-0.13, 0.05)
EQ5D3L Raw Score	84.97 (13.72)	88.72 (13.43)	0.23 (-2.44, 9.96)
Mean Axis Change*	79.62 (7.22)	30.93 (19.86)	<0.0001 (-56.30, -41.09)
WTR:ATR:O (n)	0:28:1**	8:34:13***	0.0025

Table 2: Post-operative Outcomes at 6-months follow-up.

SD=Standard deviation; UDVA=Uncorrected distance visual acuity; BDVA= Best-corrected distance visual acuity; SE=Spherical Equivalent; D=Dioptres; WTR=With-the-rule; ATR=Against-the-rule; O=Oblique.

* Change in axis defined as the difference in post-operative subjective refractive cylinder compared to pre-operative steep axis (K2) on Biometry. There was no statistically significant difference ($p=0.40$) in mean post-operative axis change between the original control group (mean 45.02° , SD 30.93) and the intervention group (mean 50.59° , SD 25.96).

**28 cases of WTR (pre-op) to ATR (post-op), 1 case of O to O.

***22 cases of ATR to ATR, 2 cases of ATR to WTR, 4 cases of ATR to O, 6 cases of WTR to WTR, 8 cases of WTR to ATR, 8 cases of WTR to O, 1 CASE OF O TO O, 4 CASES OF O TO ATR.

Chi-square test used to compare proportions of WTR, ATR and O astigmatism between the two groups. Unpaired t-test used to compare means between two groups. Mean (+/-Standard deviation).

- Table 3: Vector Analysis of the Flipped Group and the Un-flipped Group at 6-month follow-up.

	Flipped Group (n=29) Mean (SD)	Un-flipped Group (n=55) Mean (SD)	p-value (95% CI)
TIA (D)	2.22 (0.58)	2.33 (0.62)	0.43 (-0.17, 0.39)
SIA (D)	2.90 (0.76)	2.14 (0.94)	0.0003 (-1.16, -0.35)
DV (D)	0.74 (0.41)	0.93 (0.47)	0.08 (-0.02, 0.39)
AOE (Degrees)	1.69 (3.34)	4.91 (11.52)	0.15 (-1.14, 7.58)
MOE (D)	0.69 (0.36)	-0.18 (0.59)	<0.0001 (-1.11, -0.63)
CI	1.32 (0.17)	0.91 (0.28)	<0.0001 (-0.52, -0.30)

Table 3: Vector Analysis of the Flipped Group and the Un-flipped Group at 6-month follow-up.

SD=Standard deviation; CI=Confidence Interval; TIA=Target Induced Astigmatism; SIA=Surgically Induced Astigmatism; DV=Difference Vector; AOE=Angle of Error; MOE=Magnitude of Error; CI=Correction Index.

Unpaired t-test used to compare means between two groups. Mean (+/-Standard Deviation)

- Table 4: The difference in the recommended toric intraocular lens cylinder power by the online toric calculator for pre-operative WTR, ATR and Oblique astigmatism with and without inclusion of the posterior corneal astigmatism.

	Toric Intraocular Lens Cylinder Power (D)					
	Flipped (n=29) Mean (+/- SD)			Un-flipped (n=55) Mean (+/- SD)		
	No PCA	PCA	p-value	No PCA	PCA	p-value
WTR	2.59 (0.81)	2.04 (0.67)	0.01	2.86 (1.04)	2.59 (0.92)	0.36
ATR	-	-	-	2.45 (0.72)	2.86 (0.81)	0.05
Oblique	2	2	-	2.50 (0.87)	2.50 (0.87)	1.00

Table 4: The difference in the recommended toric intraocular lens cylinder power by the online toric calculator for pre-operative WTR, ATR and Oblique astigmatism with and without inclusion of the posterior corneal astigmatism.

*The mean surgically induced astigmatism (SIA) in the intervention group reduced by a mean of 0.07D (+/- 0.55) in the flipped cases, and increased by a mean of 0.14D (0.48) in the un-flipped cases.

SD=standard deviation; D=Dioptres; PCA=posterior corneal astigmatism; WTR=with-the-rule; ATR=against-the-rule.

What is already known on this topic

- Toric intraocular lenses (TIOs) result in greater spectacle independence and uncorrected distance visual acuities in cataract surgery patients with corneal astigmatism and are associated with better quality of life scores and lower economic costs for patients.
- Flipped of a patient's baseline cylinder axis following TIO implantation may lead to intolerance and lower quality of vision.

What this study adds

- This is one of the first papers to the author's knowledge assessing patient tolerance to axis-flip following cataract surgery and TIO implantation using patient reported outcome measures.
- In this cohort of patients with age-related cataract, flipping of the cylinder axis following cataract surgery and TIO implantation did not adversely affect visual acuity or patient reported outcome measures.