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ORIGINAL RESEARCH

The Incidence of Posterior Ocular Astigmatism in a Refractive Surgery Population as Determined by the Direct Reduction of Topography Measured Astigmatism

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Video abstract

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Purpose: A retrospective study to determine the incidence of posterior ocular astigmatism (POA) after removal of topography guided excimer laser ablation utilizing topography measured astigmatism and axis to remove anterior corneal astigmatism and measure residual astigmatism in 1500 eyes.

Methods: WaveLight Contoura was performed with topography measured astigmatism and axis, and all inaccurate outcomes were analyzed for the presence of low topographic astigmatism and significant residual manifest astigmatism. A secondary enhancement procedure was then performed, and measurements taken to measure the presence of topography measured astigmatism and the lack of manifest astigmatism to confirm that POA had been present.

Results: Out of the 1500 eyes, 44 were confirmed to have POA, resulting in an incidence of 2.93%. The average amount of manifest astigmatism in these eyes post-primary procedure was 1.13D, and the average topography measured astigmatism was 0.39D. After secondary enhancement with wavefront optimized ablation, the average amount of post-operative astigmatism was 0.01D, and the average amount of topography measured astigmatism was 1.11D. Post-secondary enhancement procedure, average higher-order aberration was reduced 9%.

Conclusion: The incidence of 2.93% is lower than prior estimated amounts of posterior ocular astigmatism.

Keywords: posterior ocular astigmatism, higher-order aberrations, Contoura, topography guided ablation, LASIK, PRK

Introduction

Posterior Ocular Astigmatism has never been directly measured but extrapolated in various studies to be 13–19% of eyes.[1–3] By definition, POA is all astigmatism posterior to the anterior cornea, which would include posterior corneal astigmatism, lenticular astigmatism, and retinal astigmatism.[1,3–5] Due to technical imaging constraints, none of these can be measured directly, but must be extrapolated from imaging data.[3] To detect the presence of POA with absolute certainty, all anterior corneal astigmatism must be removed to allow for the measurement of residual astigmatism, which would constitute POA. This same value has also been referred in the literature as ORA, ocular residual astigmatism.

Topography guided ablation systems utilizing topography measured astigmatism and axis are able to fully, or close to fully, remove all anterior astigmatism. The concern with such systems is that removing all topographically measured astigmatism would result in an unacceptable number of inaccurate outcomes. Indeed, the first LYRA Protocol studies demonstrated a 13% inaccuracy rate, which was defined as inaccuracy of 0.50D of astigmatism or more.[6,7]

Since that time, studies have demonstrated that there are biologic sources of inaccuracy such as one-time biomechanical change from flap creation in certain corneas, epithelial compensation of corneal HOA, as well as biologic variability in tissue removal by excimer laser ablation.[8–11] This study retrospectively examined 1500 myopic/myopic astigmatism

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eyes that had LASIK performed on the WaveLight Contoura EX500 (WaveLight GmbH, Erlangen, Germany) system with Contoura software version wps 1.51 utilizing surgical planning via the LYRA Protocol to remove anterior measured astigmatism. All inaccurate results were examined to determine causation and to specifically search for eyes with POA as the cause of inaccurate outcome. Secondary enhancement procedures, which were performed with wavefront optimized ablation, were also analyzed to determine if regular astigmatism was added to a cornea to cancel POA. Only if the patient did not have a biologic reason for error of outcome, had residual manifest astigmatism that did not match corneal topography measured astigmatism, and then had an accurate outcome by creation of astigmatism on the cornea could a patient be determined to definitively have POA.

Materials and Methods

Study Design and Population

We retrospectively examined 1500 eyes that had topography-based astigmatism and axis correction to eliminate anterior topographic astigmatism utilizing the LYRA Protocol with WaveLight Contoura topography guided ablation specifically. The inaccurate outcomes from these 1500 eyes were then analyzed to determine reason for outcome error, specifically looking for POA. The methodology used to confirm the presence of posterior ocular astigmatism was to eliminate anterior corneal astigmatism, resulting in any residual astigmatism immediately after the procedure to be suspect and examined for the presence of POA by elimination of other sources of incorrect outcomes such as epithelial compensation, biomechanical change of cornea from flap creation, and biologic variability of tissue removal by excimer laser.[8–10] The methodologies for this are outlined in the prior studies referenced, but the main goal was to find patients with little to no topography measured astigmatism but residual manifest refractive astigmatism. Further confirmation was necessary by induction of topography measured astigmatism after secondary correction with the lack of manifest refractive astigmatism. We elected not to include patients that were undergoing repair of their corneas with Contoura, ie, patients that had corneal irregularity due to ectasia, past corneal surgery, trauma, infection etc., as the source of error in these patients had too many variables to purely isolate POA. Thus, this study included only those with primary laser vision correction.

Surgical Technique and Post-Operative Care

All surgeries were either LASIK or PRK, performed by one surgeon (MM) on the WaveLight EX500 laser. All LASIK flaps were created with either the Moria M2 microkeratome or the WaveLight FS200 femtosecond laser. All PRK had epithelium removal either by excimer laser or by alcohol and had 20 seconds of 0.02% Mitomycin-C applied after the procedure. All procedures were planned with LYRA Protocol (Layer Yolked Reduction of Astigmatism) which utilizes Contoura measured astigmatism and axis with spherical equivalent sphere correction.[6,12,13]

PRK post-operative care consisted of fluorometholone 0.1% bid for 6 weeks, ofloxacin 0.3% qid × 1 week, and Prolensa qd PRN for pain during epithelial healing. Bandage contact lenses were removed with healing of the corneal abrasion which was between 4–5s days on average. LASIK post-operative care was prednisolone acetate 0.1% qid for 5 days and ofloxacin 0.3% qid for 5 days.

Imaging and Diagnostic Tools

All topographies were performed with the WaveLight Topolyzer Vario. All eyes had wavefront imaging on the Nidek OPD-Scan. Epithelial compensation was measured utilizing the Optovue epithelial mapping system on their optical coherence tomography (OCT) devices (Solix and Avanti) for the process of ruling out epithelial compensation as the source of outcome error.

Identification and Outcome Endpoints

Results were tabulated for pre- and post-operative vision, manifest astigmatism and axis, and Contoura measured astigmatism and axis. To definitively have POA, an eye must have significant residual astigmatism (specified as greater than or equal to 0.50D of cylinder) measured on 3-month or later post-operative manifest refraction and also have no

significant astigmatism on topography. Upon treatment of the manifest residual astigmatism by Wavefront Optimized ablation on the WaveLight EX500, the eye must have new induced astigmatism on topography to cancel out the POA.

To be included in the study, patients must have at least 3 months of post-operative data after the primary procedure. Due to the refractive error, virtually all patients had secondary enhancements within 6 months of initial primary procedure. After the secondary correction procedure, results and data were reported from the last post-operative visit.

Measurements of 4th order Zernike polynomials to measure higher-order aberrations (HOA) were tabulated, as were what we defined as Grouped.[14] These are HOA plus lower order sphere and astigmatism, excluding piston and tilt. The first number was measured to demonstrate higher-order aberration reduction, the second to include lower-order aberration reduction.

Ethical Considerations

All patients signed written informed consent forms allowing their data to be used in this study and published, including sample cases 1–4. This study falls under the exemption of the Health and Human Services (HHS) Policy for the Protection of Human Research Subjects 45 CFR 46.104 (d) for retrospective studies and 46.104 for exempt research, and thus, no Institutional Review Board approval was required. This study also conforms to the Declaration of Helsinki guidelines. There were no safety-related incidents that occurred or were reported to Alcon Inc. or WaveLight concerning patients involved in this study.

Results

Of the 1500 eyes, 44 eyes of 23 patients were determined to have POA, including 5 men and 17 women. The average age was 34.91 years, range 23–62 years (Table 1). Two (2) patients had 1 eye each with POA, the other 21 patients had bilateral POA (Table 1). This resulted in a 2.93% POA rate from the 1500 eyes.

Average pre-and post operative topography measured K values are in Table 2. For these 44 eyes, average pre-operative astigmatism of manifest refraction was 1.11 D (range 0–3 D), Contoura topography measured astigmatism was 1.74 D. The average difference between manifest and Contoura measured astigmatism was 0.63 D, and axis was 51 degrees. Post-primary procedure, the average manifest astigmatism was 1.13 D, while the average Contoura topography measured refraction was −0.39 D (Table 3), with an average difference between manifest and Contoura measured astigmatism of 0.74 D. After secondary enhancement, the average manifest astigmatism was 0.01D and the average Contoura measured astigmatism was 1.11 D. Each patient in this cohort had regular astigmatism present on the anterior cornea post-secondary correction canceling out the POA on manifest refraction and topography both after enhancement correction resulting in plano manifest correction.

Table 1 Patient Demographics of 44 Eyes of 23 Patients Determined to Have POA

Avg. Age (years)	Females	Males	No. Patients	No. of Eyes
34.9 Range (23–62)	18	5	23	44

Abbreviation: POA, posterior ocular astigmatism.

Table 2 Average Pre-op and Post-op K Values

	Avg K. Diopters
Pre-op	43.80
Pre-op Range	40.8–46.55
Post-op	41.41
Post-op Range	35.3–45.0

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Table 3 Preoperative and Postoperative Levels of Astigmatism

	Avg TOPO Measured Cyl (Diopters)	Avg Manifest Cyl (Diopters)	Avg. Difference Between Manifest and Contoura-Measured Astigmatism (Diopters)
Pre-op	1.74	1.11	0.63 D x 51
Pre-op Range	0.07–2.93	0.00–3.00	NA
Pre-ENH	0.39	1.13	0.74
Pre-ENH Range	0.04–0.99	0.75–2.50	NA
Post-ENH	1.11	0.01	1.1
Post- ENH Range	0.21–2.05	0.00–0.50	NA

Abbreviations: Cyl, cylinder; ENH, enhancement; D, diopter.

Table 4 lists the manifest and topography measured astigmatism pre-op, pre-secondary enhancement, and post-secondary enhancement for each eye.

After enhancement utilizing manifest refraction astigmatism and wavefront optimized ablation, 100% of the 44 eyes achieved 20/20 vision, and 70.5% of the eyes achieved 20/15 vision (Table 5). OU vision, with both eyes, was 100% 20/20 and 96% 20/15. No lines of vision were lost in any of these eyes.

The HOA and Grouped of these 44 eyes were examined. The average HOA reduction across this cohort was 9%, while the Grouped (including lower order sphere and astigmatism) was 23% (Table 6).

Table 4 Manifest and Topography Measured Astigmatism Pre-op, Pre-Secondary Enhancement, and Post-Secondary Enhancement

Eye #	Pre-op Manifest Refraction	Pre-op Topo Measured	Pre-ENH Manifest Astigmatism	Pre-ENH Measured Astigmatism	Post-ENH Measured Astigmatism	Post-ENH Manifest Astigmatism
1	−1.00, −0.25 x 160	−0.26, −1.39 x 176	x, −1.00 x 90	x, −0.09 x 122	x, - 0.61 x 3	x, −0.00 x 0
2	−1.50, −0.50 x 175	−0.27, −1.31 x 7	x, −0.75x110	x, −0.34 x 155	x, −0.64 x 177	x, −0.00 x 0
3	−2.25, −0.75 x 26	−0.38, −2.05 x 4	x, −1.00 x 85	x, −0.44 x 5	x, −1.21 x 176	x, −0.00 x 0
4	−2.50, −1.25 x 179	−0.49, −2.29 x 180	x, −1.00 x 90	x, −0.23 x 172	x, −0.97 x 178	x, −0.00 x 0
5	−0.25, −1.50 x 105	−0.83, −0.78x 126	x, −1.25 x 90	x, −0.13 x 151	x, −0.93 x 174	x, −0.00 x 0
6	−0.75, −1.50 x 73	−0.69, −0.98 x 34	x, −1.25 x 95	x, 0.14 x 143	x, −1.25 x 18	x, −0.00 x 0
7	−1.50, −3.00 x180	−0.72, −4.95 x 179	x, −1.75 x 90	x, −0.12 x 41	x, −2.05x 178	x, −0.00 x 0
8	−2.00, −3.00 x 10	−0.82, −5.82 x 8	x, −1.25 x105	x, −0.47 x 112	x, −0.71 x 4	x, −0.00 x 0
9	−7.75 SPH	−0.67, −0.58 x 14	x, −1.25 x 95	x, −0.36 x 161	x, −1.62 x 179	x, −0.00 x 0
10	−7.75 SPH	−0.52, −0.84 x 158	x, −2.50 x 95	x, −0.58 x 134	x, −2.60 x 2	X, −0.50 x 180
11	−1.25, −1.00 x 15	−0.82, −1.65 x 10	x, −1.00 x 100	x, −0.31 x 174	x, −1.28 x 3	x, −0.00 x 0
12	−2.50, −0.50 x 180	−0.93, −1.68 x 3	x, −1.25 x 100	x, −0.41 x 09	x, −1.56 x 11	x, −0.00 x 0
13	−2.50, −0.25 x 60	−0.98, −1.05 x 177	x,-1.50 x 80	x, −0.67 x 168	x, −1.48 x 175	x, −0.00 x 0
14	−2.75, −0.50 x 105	−0.86, −0.86 x 6	x, −1.00x 95	x, −0.43 x 11	x, −1.17 x 2	x, −0.00 x 0
15	−3.00 SPH	−0.53, −1.23 x 173	x, −1.00 x 90	x, −0.29 x 126	x, −0.78 x 173	x, −0.00 x 0

(*Continued*)

Table 4 (Continued).

Eye #	Pre-op Manifest Refraction	Pre-op Topo Measured	Pre-ENH Manifest Astigmatism	Pre-ENH Measured Astigmatism	Post-ENH Measured Astigmatism	Post-ENH Manifest Astigmatism
16	−2.75 SPH	−0.59, −0.89 x 16	x, −0.75 x108	x, - 0.68 x 32	x, −0.45 x 175	x, −0.00 x 0
17	−0.75, −2.50 x 175	−0.57, −3.93x 177	x, −1.00 x 95	x, - 0.56 x170	x, −1.27 x 72	x, −0.00 x 0
18	pl, −3.00 x 177	−0.53, −4.74 x 179	x, −1.50 x 93	x, - 0.40 x171	x, −1.59 x 1	x, −0.00 x 0
19	pl, −0.75 x 80	−0.44, −0.80 x 3	x, −1.50 x 95	x, −0.13 x 12	x, −1.77 x 9	x, −0.00 x 0
20	−0.25, −1.75 x 7	−0.60, −2.50 x 4	x, −1.00 x 90	x, - 0.41 x 93	x, - 0.47x 164	x, −0.00 x 0
21	−0.75, −0.75 x 7	−0.63, −1.92 x 0	x, −1.00 x 90	x, −0.04 x 109	x, −1.04 x 0	x, −0.00 x 0
22	−3.00, −1.00 x 20	−0.46, −2.30 x 13	x, −0.75 x 120	x, −0.26 x 17	x −1.03 x 19	x, −0.00 x 0
23	−1.25, −1.00 x 20	−0.48, −1.75 x 15	X, −0.00 x 0	x, −0.27 x 123	x, 0.21 x 2	x, −0.00 x 0
24	−5.50, −0.50 x 180	−0.62, −1.66 x 177	x, −1.00 x 85	x, 0.95 x 179	x, 1.46 x 003	x, −0.00 x 0
25	−5.50, −0.75 x 3	0.68, −1.48 x 178	x, −1.00 x110	x, −0. 51 x171	x, −0.83 x 9	x, −0.00 x 0
26	−2.50, −0.50 x 115	−0.55, −0.77 x 178	x, −0.75 x 85	x, −0.26 x 26	x, −1.04 x 4	x, −0.00 x 0
27	−2.75, −0.50 x 93	−0.50, −0.07 x 166	x, −0.75 x 90	x, −0.07 x 70	x, - 0.86 x178	x, −0.00 x 0
28	−7.00, −0.50 x 5	−0.34, −1.86 x 177	x, −0.75 x 93	x, −0.99, 173	x, −1.36 x 178	x, −0.00 x 0
29	−7.00, −0.50 x 5	−0.17, −1.51 x 174	x, −1.00 x 102	x, −0.62 x 164	x, −0.89 x 3	x, −0.00 x 0
30	−2.00, −1.25 x 5	−0.49, −2.78 x 177	x, −1.25 x 90	x, −0.84 x 171	x, −1.97 x 180	x, −0.00 x 0
31	−1.50, −1.25 x 180	−0.62, −2.61 x 2	X, −1.25 x 110	x, −0.48 x 166	x, −1.32 x 7	x, −0.00 x 0
32	−0.25, −2.25 x 115	+0.02, −1.30 x144	x, −1.00 x 95	x, −0.61 x 171	x, −1.23 x 172	x, −0.00 x 0
33	−1.75, −2.25 x 70	−0.03, −1.08 x 52	x, −1.00 x 90	x, −0.62 x 8	x, −1.13 x 3	x, −0.00 x 0
34	−4.00, −0.50 x 125	−0.67, −1.28 x 163	x, −0.75 x 75	x, −0.49 x 171	x, −1.47 x 169	x, −0.00 x 0
35	−4.50, −0.50 x 10	−0.69, −1.18 x 17	x, −0.75 x105	x, −0.42 x 15	x, 1.06 x 123	x, −0.00 x 0
36	−2.50, −1.25 x 10	−0.46, −2.32 x 9	x, −1.00 x 100	x, −0.84 x 2	x, −1.71 x 7	x, −0.00 x 0
37	−2.75, −1.75 x 7	−0.42, −2.38 x 4	x, −1.00 x 110	x, −0.65 x 172	x, −1.51 x 05	x, −0.00 x 0
38	−0.75, −2.50x 98	−0.85, −0.90 x 100	x, −1.25 x 85	x. −0.16 x 151	x, - 1.1, x 161	x, −0.00 x 0
39	+0.50, −2.25x 89	−0.89, −0.56 x 115	x, −1.25 x 90	x, −0.29 x 80	x, −0.53 x 12	x, −0.00 x 0
40	−2.25 SPH	−0.56, −1.45 x 179	x, −1.00 x 75	x, −0.51 x 14	x, −1.24 x 173	x, −0.00 x 0
41	−2.00 SPH	−0.67, −1.58 x 7	x, −1.00 x 110	x, −0.61x 163	x, −1.21 x 179	x, −0.00 x 0
42	−0.50, −1.00 x 155	−0.59, −2.07 x 178	x, −1.50 x 90	x, −0.40 x 29	x, −1.58 x 7	x, −0.00 x 0
43	pl. −1.00 x 105	−0.10, −0.89 x 175	x, −1.50 x 85	x, −0.50 x 145	x, −1.41 x 170	x, −0.00 x 0
44	−0.50, −1.00 x 90	−0.15, −0.56 x 10	x, −1.00 x 95	x, −0.28 x 13	x, −1.18 x 3	x, −0.00 x 0

Abbreviation: ENH, enhancement.

Statistical testing was performed via *t*-test to determine the significance of various factors in the breakdown of the data of the 44 patients diagnosed with POA out of the 1500 original eyes. These were used to attempt to determine statistical comparisons to try and determine patterns in the group of 44 patients. Since this group is so small it is difficult to form statistical determinations and patterns within it. Comparisons were performed utilizing single tailed t-tests (Table 7). *T*-test results indicated that the difference between average HOA between the pre-op and post-secondary enhancement was not statistically significant

Table 5 Visual Outcomes of Following Secondary Enhancement Surgery

	No. Eyes	Avg. Percentage	No. Patients (OU)	Avg. Percentage
20/20 or better	44	100%	23	100%
20/15 or better	31	70.45	22	95.7%

Abbreviation: OU, right eye.

Table 6 Zernike Polynomials for 4th Order Higher-Order Aberrations and for Grouped Polynomials for 23 Patients One Month Post-op Secondary Procedure

	HOA 5	Grouped
Pre-op avg. microns (Range)	0.167 (0.0842–0.2630)	0.358 (0.106–0.850)
Post-op avg. microns (Range)	0.152 (0.0562–0.292)	0.276 (0.109–0.601)
Avg. Reduction	9.00%	22.8%

Abbreviation: HOA, higher order aberration.

Table 7 T-Tests for HOA, Grouped, Cylinder, and Axis Before and After Secondary Enhancement Surgery

	T-Test Values
HOA 5 Pre-op to post-secondary enhancement	0.2027
Grouped Pre-op to post-secondary enh.	0.0034
Pre-op topo cyl to pre- op manifest cyl	<0.0001
Pre- op topo axis and pre-op manifest axis	0.0827
Pre-op manifest cyl and pre-enh manifest cyl	0.4162
Pre-op manifest axis and pre-enh manifest axis	0.03754
Pre-op topo cyl to pre-enh manifest cyl	0.0004
Pre- op topo axis to pre-enh manifest axis	0.4810
Pre-op enh measured Cyl to pre-enh manifest Cyl	<0.0001
Pre-op enh measured axis to pre-enh manifest axis	0.05802
Post-op enh measured Cyl to post-enh manifest Cyl	<0.0001
Post-op enh measured axis to post-enh manifest axis	<0.0001

Abbreviation: Cyl, cylinder.

($p = 0.2027$), while the same comparison for Grouped was statistically significant ($p = 0.0034$). The difference between average pre-op manifest astigmatism vs pre-op Contoura measured astigmatism was statistically significant ($p < 0.0001$), but the difference between average axis was not ($p = 0.0827$). The difference between average pre-op manifest cylinder and average pre-enhancement manifest cylinder was not statistically significant ($p = 0.4162$) while the average axis of the same comparison was statistically significant ($p = 0.03754$). The difference between pre-op average Contoura measured cylinder to average pre-enhancement manifest cylinder was statistically significant ($p = 0.0004$) while the average axis of the same comparison was not ($p = 0.4810$). Pre-enhancement average Contoura measured cylinder to pre-enhancement average manifest cylinder was statistically significant ($p < 0.0001$) while the axis for the same comparison was not ($p = 0.0582$). Post-enhancement comparison

of post-op enhancement Contoura measured cylinder and axis to post-op manifest cylinder and axis were statistically significant ($p < 0.0001$) and ($p = p<0.0001$).

Discussion

Determining the incidence of POA is important due to its impact on all types of refractive and ophthalmic surgery. Current technology is based on optical imaging and is unable to directly measure POA in isolation, and estimates have been extrapolated from said imaging.[5] Since POA by definition is all astigmatism posterior to the anterior cornea, the most accurate way would be to have a large dataset that removed anterior topographic astigmatism to determine the percentage of eyes that had residual manifest astigmatism. This was performed on 1500 consecutive eye which had treatment with topography guided ablation utilizing topography measured astigmatism and axis (specifically WaveLight Contoura Measured) utilizing LYRA Protocol, which uses the full magnitude of Contoura measured astigmatism as well as the measured axis with adjustment to the sphere of the difference in spherical equivalent between the measured and manifest astigmatism.[6,12,13] Analysis of all inaccurate outcomes resulted in 44 eyes that had POA as confirmed by the presence of low levels of topography measured astigmatism post-operatively while still having significant levels of post-operative manifest astigmatism. Logically, treatment of this residual astigmatism with Wavefront Optimized ablation resulted in a decrease in manifest astigmatism and a corresponding increase in topography measured astigmatism (Table 3 and Table 4). This resulted in 44 eyes in this 1500 eye cohort that fit all of these parameters resulting in a POA percentage of 2.93%.

The average amount of post-primary procedure manifest astigmatism was 1.13D, and the Contoura topography measured was 0.39D. Post-secondary enhancement thus had reversed, with the manifest astigmatism being 0.01 D and the Contoura topography measured astigmatism averaging 1.11 D. This demonstrated the creation of regular astigmatism on the cornea to cancel out the POA.

2.9% is a small percentage of overall eyes, and this is lower than prior estimates of POA.

A prior study which estimated the incidence of POA was Lin et al, which used vector calculations to calculate the difference between manifest astigmatism and anterior corneal astigmatism and determined the incidence of POA was 18.08%.[1] Alpins, the inventor of the vector astigmatism calculation method, stated that clinical refractive astigmatism and anterior corneal astigmatism are rarely identical in magnitude and axis, and termed the vector difference ocular residual astigmatism (ORA) but did not provide an incidence of ORA.[15] ORA defines sources of refractive astigmatism other than the anterior cornea, which is the same definition as POA. All of the publications we found during an extensive literature search calculated ORA utilizing the same vector calculations but did not establish an overall incidence of ORA. No other study was found that directly removed anterior corneal astigmatism to determine the incidence of POA/ORA.

Due to this lack of other studies for context, further literature searches were performed to determine if there were publications that provided some incidence of refractive astigmatism posterior to the anterior cornea. Hosny et al published a paper that utilized vector calculations with the Alpins method to determine that posterior corneal astigmatism represented 30% of total corneal astigmatism.[16] POA/ORA comprises all sources of astigmatism posterior to the anterior cornea which includes posterior corneal astigmatism. Wallerstein et al in a Research Letter to Clinical Ophthalmology compared refractive (manifest) astigmatism to anterior corneal astigmatism magnitude, utilized data from other studies for posterior corneal astigmatism, and posited that the interaction between posterior and anterior corneal astigmatism was a major reason for the difference between anterior corneal astigmatism and refractive astigmatism and not any interaction between corneal higher order aberrations and anterior corneal astigmatism. Their data and analysis of the literature stated that posterior corneal astigmatism compensates between 22% and 31% of the anterior corneal astigmatism.[17] Although it is possible that other posterior ocular astigmatism sources could cancel out and reduce this 30% number, this incidence number itself may be incorrect as studies with topography guided ablation with topography measured astigmatism have not had anywhere near a 30% error in outcome rate.[6,18]

This would indicate that treatment of the anterior corneal astigmatism would cause inaccuracy in 22–31% of eyes, but again there is no full analysis of how other sources of POA/ORA could also influence and cancel out the impact of the difference in posterior corneal astigmatism. Again, all of these studies used estimates based on astigmatism vector calculations, and not direct removal of the anterior corneal astigmatism to determine residual refractive astigmatism.

We believe that this study is the first to attempt to directly determine an incidence of POA by removing anterior topography-based astigmatism with topography guided ablation, and then also confirming the presence of POA by a net plano refractive astigmatism measurement with topographic astigmatism present on the cornea. At this time, it is unknown why this incidence is significantly different from that estimated via vector calculations. It may well be that vector astigmatism calculation formulas have some unknown error, that vector astigmatism calculations are not an accurate method to determine POA incidence, or that there is some unknown error in our direct methodology measurement.

The average of the magnitude of POA determined by manifest astigmatism post-operatively in these patients was 1.13D, with a range of 0.75 to 2.50, and thus the average magnitude of POA in this study is approximately 1 diopterThis 2.9% POA incidence, which is lower than estimated in prior studies as discussed above, may also be due to the fact that biological-based changes that resulted in inaccurate outcomes such as biomechanical change from flap creation, epithelial compensation of higher-order aberration resulting in incomplete reduction of corneal stromal HOA, and biological differences in removal of tissue by excimer laser between corneas were incorrectly categorized as POA.[8–10] These phenomena have only been described more recently, and further study needs to be done to further understand biological sources of error.

One of the advantages of topography guided excimer laser ablation based on topography measured astigmatism and axis is the creation of a more uniform cornea resulting in lowered HOA.[19,20] This average HOA pre-op to post-secondary enhancement was reduced by 9%, which T testing indicated was not statistically significant, but Grouped which is HOA plus lower-order sphere and astigmatism was lowered 23%, which was statistically significant. One of the problems with the HOA and Grouped measurements was the lack of proper follow-up. Although all patients had a minimum of 3 months between primary and secondary procedure, some patients did not return for the 3-month post-secondary procedure exam and this may have affected the HOA measurements. This HOA reduction is notable in light of the fact that each of these eyes had two procedures performed – a topography guided primary procedure and a wavefront optimized secondary procedure – which could increase the likelihood of an increase in overall HOA. It is also notable that creating regular astigmatism on the cornea for the secondary enhancement also did not result in an overall average HOA increase for these eyes.

Limitations of this study are the need to confirm the data with other datasets directly removing anterior topography measured astigmatism to determine residual refractive astigmatism to determine POA. The 2.9% incidence rate resulted in a relatively small group of eyes (44) making further patterns to understand POA difficult. A further limitation is the lack of correlation of incidence with vector astigmatism calculation studies, which although estimates, have been relied upon by multiple other studies. The final HOA data is limited by the uneven follow up post-secondary enhancement by patients.

In conclusion, POA appears to be present in a smaller percentage of eyes than prior estimates and may have been over-estimated as the cause of prior inaccurate outcomes. This study should be confirmed with other datasets and studies that directly remove anterior topography astigmatism to determine residual refractive astigmatism. Even though 1500 eyes are a large cohort, cohorts from other surgeons would help refine the actual percentage of eyes with POA.

Abbreviations

D, diopter; HHS, Health and Human Services; HOA, higher-order aberration, LASIK, Laser-assisted in situ keratomileusis; OCT, optical coherence tomography; POA, posterior ocular astigmatism; PRK, photorefractive keratectomy; PRN, as needed; qd, once daily; qid, four times daily.

Disclosure

Dr Manoj Motwani discloses he has been granted United States patent no. 108570352 concerning the creation of a more uniform cornea utilizing the topography measured astigmatism, and United States patent no. 108570353 for the treatment of epithelial compensation of corneal irregularity in conjunction with the use of topography guided ablation system. These patents are the basis for the LYRA/San Diego/CREATE Protocols.[6,12,13,21] The author also has patents pending for an integrated system for creating a complete treatment map of the Ocular Focusing System that would be able to detect the presence of POA and treat with topography guided ablation on the anterior cornea. LYRA/San Diego/CREATE Protocols may be considered competitive to other procedures or surgical planning systems such as wavefront guided, wavefront optimized, topography guided with manifest refraction, and surgical planning software such as Phorcides or ZZ. The authors report no other conflicts of interest in this work.

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