Original Article

The influence of routine uncomplicated phacoemulsification on the orthogonality of the cornea

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Purpose: The aim of this study was to determine the effect of routine uncomplicated phacoemulsification on the orthogonal distribution of mass within the central optical zone of the cornea. **Methods:** Astigmatism at both corneal surfaces was evaluated using Orbscan II (Bausch &and Lomb) before and up to 3 months after routine phacoemulsification (one eye/patient). The data were subjected to vector analysis to estimate the pre-and postoperative total astigmatism of the cornea (TCA). **Results:** Reporting the chief findings in minus cylinder (diopters, DC) over the central 3 mm (A) and 5 mm (B) optical zones. Mean TCA powers (±sd) at pre- and 3-months postop were A) –4.45DC (±2.00) and –5.69DC (±2.69), B) –2.91DC (±2.22) and –2.71DC (±1.60). Change in mean power was significant over 3 mm ($P < 0.01$, $n = 49$) but not over 5 mm. Inter-zonal differences were significant ($P < 0.01$). There was a significant linear relationship between the change in TCA power (y = preoperative-postoperative) and TCA at preoperative stage (x) where, A) $y = 0.45x + 3.12$ ($r = 0.336$, $n = 49$, $P = 0.018$), B) $y = x + 2.65$ ($r = 0.753$, $n = 49$, $P = <0.01$). Over the central 3 mm zone only, change (preoperative-postoperative) in axis (°) of TCA (y_1) was significantly associated with TCA axis at preoperative stage (x_1) where $y_1 = 1.391x_1 - 0.008x_1^2 - 0.701$ ($r = 0.635$, $n = 49$, $P < 0.01$). **Conclusion:** Changes in TCA power and axis at 3 months postop, determined using Orbscan II, are indicative of orthogonal alterations in the distribution of corneal tissue. Over the central 3 mm zone, the association between y_1 and x_1 shows that a change in TCA axis is more profound when preoperative axis is near 90° i.e., against-the-rule.

Key words: Astigmatism, corneal, surface, total

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Corneal pachymetry could change after phacoemulsification.[1-4] Any regional variations of pachymetric changes suggest that there is a nonuniform shift in the distribution of mass over the cornea. The introduction of Scheimpflug-based corneal imaging systems led to the creation of two-dimensional topographic pachymetry maps that can be obtained with great speed and precision. These systems also generate elevation maps and the astigmatic powers of both corneal surfaces.[5] Many Placido disk-based corneal topographers generate the shape of the front surface along each meridian and the corresponding shape of the back surface is derived using the pachymetric data defining the distances separating the two surfaces at set points along each meridian. The complex working algorithm evolved from basic trigonometric methods used by earlier investigations on the topography of the posterior corneal surface.[6,7] Now the computations along each axis are used to build up a three-dimensional picture of both surfaces. The averaged maximum and minimum powers over set chord diameters are displayed along the respective axes. Thus, the astigmatic components at both corneal surfaces can be used to model the cornea as a single bitoric lens. Should the astigmatism at one surface change but the astigmatism at the other remained constant then we can conclude that the distribution of mass within the cornea has altered in an orthogonal manner. Phacoemulsification can alter the astigmatism of both corneal surfaces, and this affects the total astigmatism of the cornea (TCA), as observed using Scheimpflug-based systems.[8-12] Is a change in TCA predictable? Can such changes be detected using a Placido disc-based system? Does any longitudinal change in total corneal astigmatism follow a pattern? If such a pattern should occur, does the nature of the pattern depend on characteristics of the preoperative corneal astigmatism?

The purpose of this study was to address these questions by monitoring the astigmatism at both corneal surfaces, over two-chord diameters, and calculating the total corneal astigmatic power and axis before and after routine uncomplicated phacoemulsification.

Methods

Measurement of corneal surface astigmatism

Orbscan II (Bausch & Lomb, Rochester, NY, version 3.2) is a Placido disc, scanning slit, servo-controlled system that

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captures data from 9,000 loci over the corneal surface to generate two-dimensional dioptric power maps, of both corneal surfaces and thickness distribution. The scanning slit provides the distance separating the two corneal surfaces at each location over the anterior corneal surface. These data, in conjunction with the dioptral power map generated for this surface, are used to construct an axial dioptric power map of the posterior surface. These computations are used to average the astigmatism at both corneal surfaces over central chord diameters of 3 mm and 5 mm. The calculations of corneal posterior surface powers are based on refractive index values of 1.376 for the cornea and 1.336 for the aqueous humor. Fig. 1 (a and b) is a typical example of pre- and postop Orbscan readouts showing changes in anterior and posterior corneal surface topographies, astigmatic powers and axes over 3 and 5 mm and thickness distribution. Full descriptions of Orbscan functionality are provided elsewhere.[5,13]

Calculation of total corneal astigmatism (TCA)

The surface astigmatic data were subjected to vector analysis using a simple modification[14] of the procedure advanced by Alpins.[15] The total astigmatic power of the cornea was calculated at preop, 1, 2, and 3 months postop. In addition, the difference (Δθ) between the angle of TCA at the pre- and postoperative stages was also determined. This would indicate if any change in the angle was associated with the preop astigmatic angle. The actual change in TCA, that is the change induced by the surgery itself (SIA), was also calculated. However, from the outset the focus of this paper was primarily on TCA not SIA.

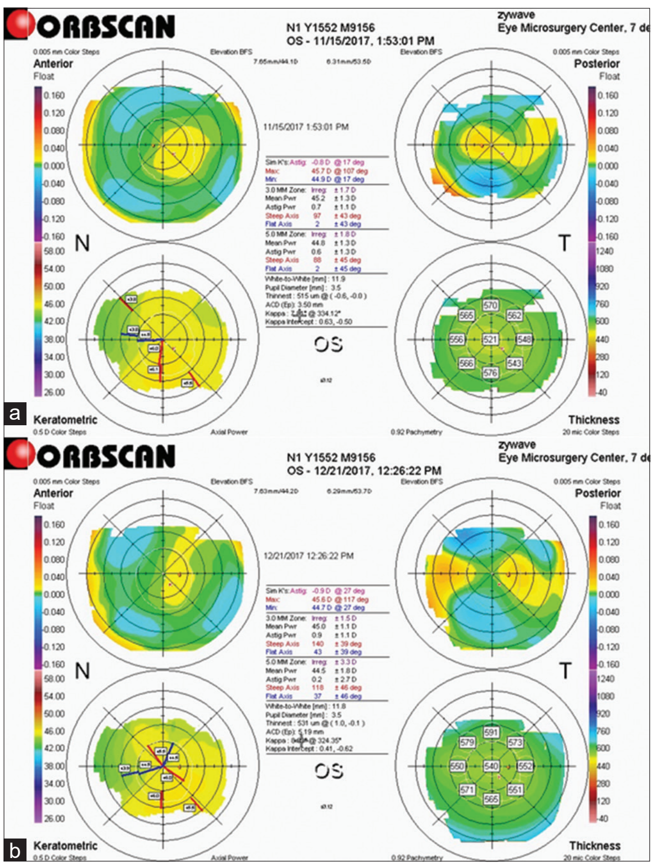

Figure 1: Example of Orbscan plots before (a) and after (b) phacoemulsification. The screenshots show topography of both corneal surfaces, distribution of corneal thicknesses and astigmatic powers and axes over the central 3 and 5mm central zones for the anterior surface. In a similar manner, the functionality of the instrument also yields astigmatic values for the posterior surface. Differences in both surface astigmatism and thickness are observed by glancing over the two images

Study design

The investigation was a prospective consecutive nonmasked single-center observational study that was approved by the local ethics committee and followed the tenets of the Declaration of Helsinki. All subjects signed consent forms after the aims and procedures of the investigation were fully explained. Data were harvested from 103 subjects on a consecutive, case-by-case, basis. Only measurements from right eyes were included for statistical purposes in bilateral cases.

Exclusion criteria

Subjects presenting with general health conditions or any characteristics that could impact on the outcomes of routine phacoemulsification were excluded. Other than the need for cataract surgery, none of the subjects enrolled had any history of active or previous ocular conditions involving the anterior or posterior segment.

Description of preoperative preparation, surgery, and post-operative treatment

Preoperatively, the horizontal meridian of the cornea was marked by one examiner (LT) in each treated eye using a slit-lamp-marking technique under topical anesthesia before pupil dilation. Patients were asked to place their chin on the chinrest with the forehead pressed firmly against the fixed head support. The slit beam was adjusted to minimal width, rotated to the horizontal, and placed over the pupil center. To ensure both eyes were positioned along a single line, the slit lamp was

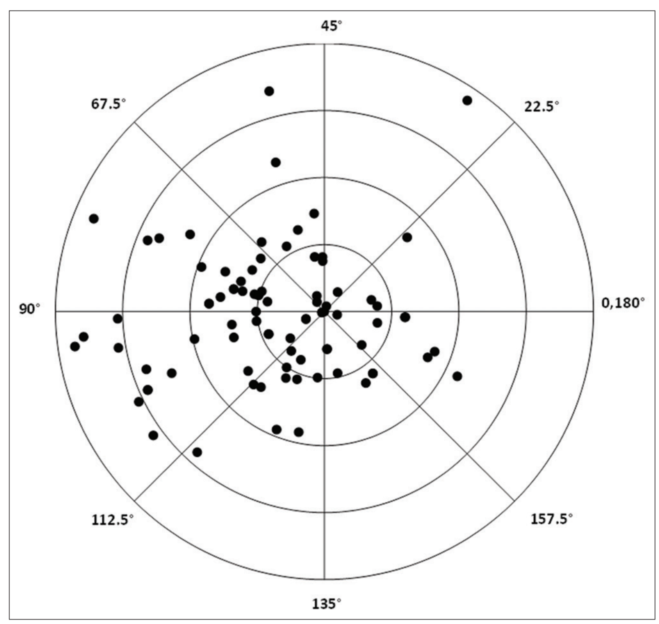

Figure 2: The double-angle plot showing the actual changes in total corneal astigmatism (ie the changes induced by surgery itself and commonly referred to as the surgically induced astigmatism or SIA) at 1 month postop over central 3mm optical zone. Each circle represents SIA power of 2DC. Most data points occupy the left side indicating that the SIA, over this central zone, was more inclined towards 90° (ie along the vertical) less so towards 180° (ie the horizontal)

moved to the contralateral eye. When the first Purkinje reflexes of both eyes were aligned at the same height, the slit lamp was then moved to the treated eye without changing the height of the slit lamp. The horizontal meridian was marked by gently scratching the cornea at the limbus at three and nine o'clock positions against the middle of the slit with a 30-gauge sterile needle and staining of corneal microabrasions with the 2% collargoli solution (colloidal silver solution).

Routine uncomplicated phacoemulsification was performed by one surgeon (LT) under topical anesthesia through a 2.2 mm self-sealing clear corneal incision. To minimize variability due to surgery alone, in all cases a corneal tunnel was made at 12 o'clock using a Mendez ring and referring to the preoperative marks. The paracenthesis of 1.2 mm were made at three and nine o'clock according to the preoperative marks. Circular capsulorhexis of 5.0 mm was followed by lens hydrodissection, phacoemulsification, and bimanual cortex removal using Infinity Vision System (Alcon Surgical, Inc). The hydrophobic acrylic one-piece monofocal IOL was inserted into the capsular bag. The surgical wound was closed by stromal hydration. Surgery was completed with injections of dexamethasone (subconjunctival) and betamethasone (parabulbar). Postoperative treatment included drops of levofloxacin, dexamethasone and indomethacin with a gradual tapering off, dexpanthenol gel and a combination of trehalose and hyaluronic acid. IOP was within normal limits and no complications were observed at all examinations postoperatively.

Pre- and postoperative assessment of corneal topography

All eyes were measured using a single calibrated and recently serviced Orbscan II (Bausch & Lomb, Rochester, New York, version 3.2) instrument set at an acoustic equivalent correction of 0.92. The instrument settings were adjusted to generate topographic power maps of both corneal surfaces including mean astigmatic powers and axes over the central 3 mm and 5 mm optical zones and used as directed in the user's handbook. The data of anterior and posterior surface astigmatism (dioptres) and axes (°) over the 3 and 5 mm optical zones were harvested for analysis. Patients were checked at preop, 1, 2, and 3 months postop.

Statistical analysis

Data were stored on an Excel spreadsheet (Microsoft, Redmond, Washington) and analyzed in three stages. Firstly, to determine the significance of any apparent difference between pre-and postop values of TCA, anterior corneal surface astigmatism (ACA), and posterior corneal surface astigmatism (PCA) (paired *t* test). Secondly, to determine if there was any association between any change in TCA, ACA, and PCA with the corresponding preop values (Pearson correlation coefficient [*r*]), Thirdly, depending upon the outcomes of the second stage, to determine the significance of any apparent change in the axis (Δθ) of TCA, ACA, and PCA with the corresponding preop values (Pearson correlation coefficient [r]). Equivalent nonparametric tests were planned for application when data were not normally distributed. The significance level was set at $P < 0.05$.

Results

A total of 103 eyes (103 patients) underwent implantation of monofocal IOLs. There were 53 males and 50 females of mean age 69.5 ± 10.4 years (range 40–90 years). Ninety-two returned for planned follow-up at 1 month, 83 at 2 months and 49 at 3 months. All 103 patients were implanted with a hydrophobic acrylic 1-piece monofocal IOL either SN6AT3 ($n = 1$), SN6AT5 ($n = 1$), SN60AT ($n = 50$) or SN60WF ($n = 51$), [Alcon Surgical, Inc]. The chief results are shown in Table 1 and Figs. 2-6.

Compared with the preop values, significant changes in total corneal astigmatism (TCA) and posterior corneal astigmatism (PCA) over the central 3 mm zone were detected at all three postop sessions. Over the central 5 mm zone, significant changes in TCA were found at 1 and 2 months postop, but only at 1 month postop for PCA. Differences in TCA, and PCA, between the two optical zones was significant at preop and all three postop sessions ($P < 0.01$). For the anterior corneal astigmatism (ACA), the apparent differences between the two zones were not significant ($P > 0.05$) at any stage during the investigation. There were no significant changes in the mean axis of TCA, PCA, and ACA ($P > 0.05$).

Association between change in TCA (ΔTCA), ACA (ΔACA and PCA (ΔPCA) powers with preop values

Some significant associations were revealed and the equations of the least-squares regression lines were as follows. At 1 month postop over the 3 mm zone:

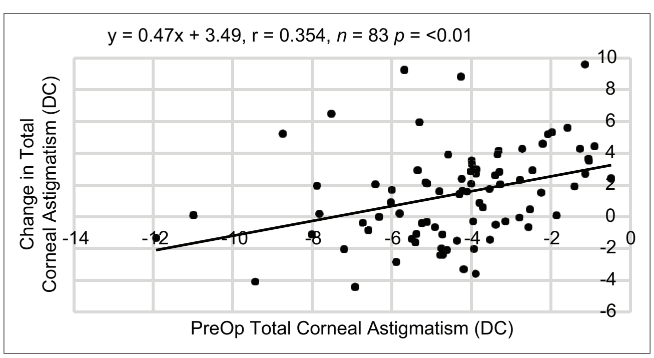

Figure 3: Change in total corneal astigmatism (y) at two months postop and preop total corneal astigmatism (x) over central 3mm optical zone. The association between the 2 parameters is represented by y = 0.47x+3.49 (r = 0.354, n= 83, p=<0.01)

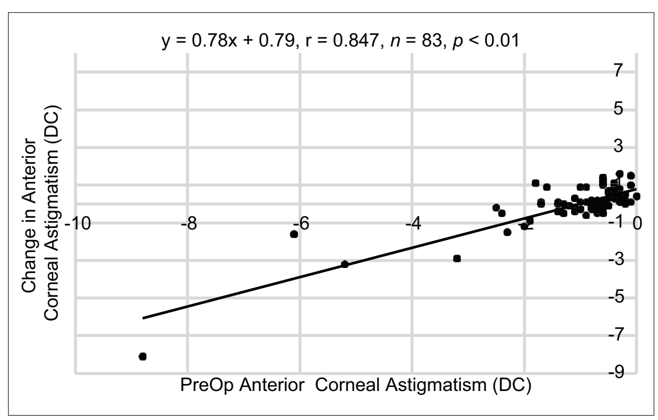

Figure 4: Change in anterior corneal astigmatism (y) at two months postop and preop anterior corneal astigmatism (x) over central 3mm optical zone. The association between the 2 parameters is represented by y = 0.78x+0.79 (r = 0.847, n=83, p<0.01).

Table 1: Mean pre-and postop astigmatic power (DC, diopters), standard deviation (±sd) and 95% confidence intervals for total corneal astigmatism (TCA), anterior (ACA) and posterior (PCA) corneal surface astigmatism over central 3mm then 5mm optical zones. The corresponding axes values are shown below the powers. The significance of differences between pre- and postop values are noted by the p values. Apparent differences between pre-and postop values for the axes were not significant (*p*>0.05)

	Preop mean (±sd), CI 95%	Postop mean (±sd), CI 95%	*P*
1 month (*n*=92)			
TCA	-4.58 (2.07), -4.16 to -5.00 93.0 (20.7), 88.8 to 97.2	-6.15 (2.75), -5.59 to -6.71 94.3 (21.5), 89.9 to 98.7	<0.01
ACA	-0.98 (1.12), -0.75 to -1.21 92.5 (53.4), 82.8 to 105	-1.16 (0.85), -0.99 to -1.33 85.5 (62.6), 72.7 to 98.3	0.225
PCA	-4.42 (2.12), -3.97 to -4.87 93.7 (15.5), 90.5 to 96.9	-5.73 (2.84), -5.15 to -6.31 92.9 (23.3), 88.1 to 97.7	<0.01
TCA	-2.71 (2.54), -2.19 to -3.23 89.0 (49.9), 79.7 to 100	-3.64 (2.64), -3.10 to -4.18 89.3 (45.7), 80 to 98.6	0.017
ACA	-0.99D (1.06), -0.77 to -1.21 90.9 (57.5), 79.2 to 103	-1.40D (1.27), -1.14 to -1.66 93.6 (67.8), 79.7 to 108	0.021
PCA	-2.47 (1.84), -2.09 to -2.85 90.3 (50.5), 80 to 101	-3.65 (2.65), -3.11 to -4.19 89.2 (51.6), 78.7 to 99.7	<0.01
2 months (*n*=83)			
TCA	-4.41 (2.21), -3.94 to -4.88 93.0 (22.5), 88.2 to 97.8	-5.83 (2.97), -5.19 to -6.47 95.9 (11.7), 93.4 to 98.4	<0.01
ACA	-1.03 (1.28), -0.76 to -1.31 95.0 (53.0), 83.6 to 106	-1.02 (0.69), -0.87 to -1.17 86.7 (60.7), 73.6 to 99.8	0.229
PCA	-4.37 (2.32), -3.87 to -4.87 92.3 (20.4), 87.9 to 96.7	-5.58 (2.90), -4.96to -6.20 95.4 (12.0), 92.8 to 98	<0.01
TCA	-2.53 (2.02), -2.09 to -2.96 86.5 (50.6), 75.6 to 97.4	-3.31 (2.18), -2.84 to -3.78 97.4 (38.5), 89.1 to 106	0.019
ACA	-1.10 (1.25), 0.83 to -1.37 91.7 (57.1), 79.4 to 104	1.26 (1.12), -1.02 to -1.50 84.5 (64.9), 70.5 to 98.5	0.229
PCA	-2.45 (1.85), -2.59 to -2.85 89.7 (51.9), 78.5 to 101	-2.99 (1.84), -2.59 to -3.39 95.3 (43.5), 85.9 to 105	0.058
3 months (*n*=49)			
TCA	-4.45 (2.00), -3.89 to -5.01 87.7 (20.6), 82 to 93.6	-5.69D (2.64), -4.95 to -6.43 91.3 (18.1), 86.2 to 96.4	0.010
ACA	-0.98 (1.42), -0.58 to -1.38 91.3 (51.7), 76.8 to 106	-0.95 (0.62), -0.88 to -1.12 92.9 (61.9), 75.6 to 110	0.889
PCA	-4.25 (2.04), -3.68 to -4.82 90.3 (14.6), 86.2 to 94.4	-5.43 (2.64), -4.69 to -6.17 95.3 (14.6), 91.2 to 99.4	0.014
TCA	-2.91 (2.22), -2.29 to -3.53 85.0 (49.4), 71.2 to 98.8	-2.71 (1.60), -2.26 to -3.16 86.9 (40.3), 75.6 to 98.2	0.600
ACA	-1.11 (1.41), -0.72 to -1.51 84.7 (55.6), 69.1 to 100	-1.04 (0.73), -0.84 to -1.24 89.2 (63.4), 71.4 to 107	0.749
PCA	-2.66 (1.85), -2.14 to -3.18 84.1 (50.3), 70 to 98.2	-2.72 (1.69), -2.25 to -3.19 89.0 (47.1), 75.8 to 102	0.864

$\Delta TCA = 0.43\ TCA + 3.52$ ($r = 0.334$, $n = 92$, $P = <0.01$), eq. 1.

$\Delta ACA = 0.88\ ACA + 1.04$ ($r = 0.762$, $n = 92$, $P = <0.01$), eq. 2.

$\Delta PCA = 0.57\ PCA + 3.85$ ($r = 0.333$, $n = 92$, $P = <0.01$), eq. 3.

And, over the 5 mm zone:

$\Delta ACA = 0.56\ ACA + 0.96$ ($r = 0.450$, $n = 92$, $P = <0.01$), eq. 4.

$\Delta PCA = 0.57\ PCA + 2.61$ ($r = 0.385$, $n = 92$, $P = <0.01$), eq. 5.

A significant association between ΔTCA and TCA was not revealed ($r = -0.087$, $n = 92$, $P > 0.05$).

At 2 months postop over the 3 mm zone:

$\Delta TCA = 0.47TCA + 3.49$ ($r = 0.354$, $n = 83$, $P = <0.01$), eq. 6.

$\Delta ACA = 0.78\ ACA + 0.79$ ($r = 0.847$, $n = 83$, $P = <0.01$), eq. 7.

$\Delta PCA = 0.46\ PCA + 3.21$ ($r = 0.375$, $n = 83$, $P = <0.01$), eq. 8.

And, over the 5 mm zone:

$\Delta TCA = 0.73TCA + 2.63$ ($r = 0.575$, $n = 83$, $P = <0.01$), eq. 9.

$\Delta ACA = 0.85\ ACA + 1.09$ ($r = 0.694$, $n = 83$, $P = <0.01$), eq. 10.

$\Delta PCA = 0.70\ PCA + 2.25$ ($r = 0.591$, $n = 83$, $P = <0.01$), eq. 11.

At 3 months postop over the 3 mm zone:

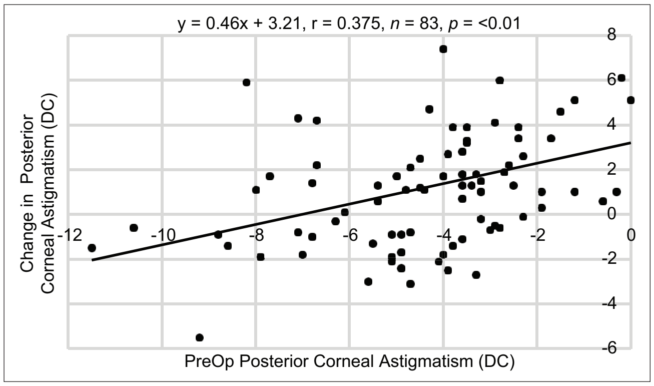

Figure 5: Change in posterior corneal astigmatism (y) at two months postop and preop posterior corneal astigmatism (x) over central 3mm optical zone. The association between the 2 parameters is represented by y = 0.46x+3.21 (r = 0.375, n=83, p=<0.01).

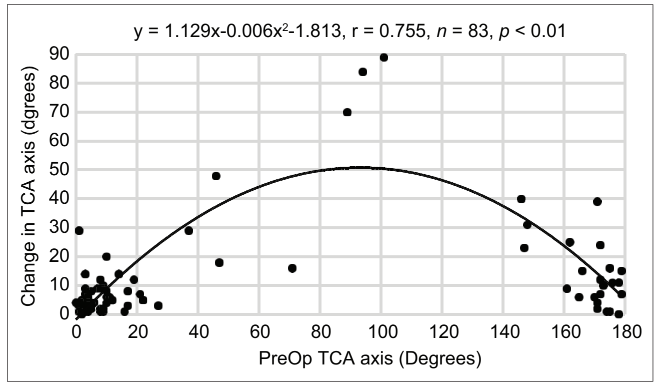

Figure 6: Change in axis of total corneal astigmatism(y) at two months postop and axis of preop total corneal astigmatism(x) over central 3mm optical zone. The association between the 2 parameters is represented by $y = 1.129x - 0.006x^2 - 1.813$ (r= 0.755, n=83, p<0.01).

$\Delta TCA = 0.45TCA + 3.12$ ($r = 0.336$, $n = 49$, $P = 0.018$), eq. 12.

$\Delta ACA = 0.98ACA + 0.94$ ($r = 0.913$, $n = 49$, $P = <0.01$), eq. 13.

$\Delta PCA = 0.59PCA + 3.61$ ($r = 0.423$, $n = 49$, $P = <0.01$), eq. 14.

And, over the 5 mm zone:

$\Delta TCA = TCA + 2.65$ ($r = 0.753$, $n = 49$, $P = <0.01$), eq. 15.

$\Delta ACA = 0.90\ ACA + 0.92$ ($r = 0.871$, $n = 49$, $P = <0.01$), eq. 16

$\Delta PCA = 0.94\ PCA + 0.25$ ($r = 0.711$, $n = 49$, $P = <0.01$), eq. 17.

Figs. 3–5 show the relationships between ΔTCA, ΔACA, and ΔPCA with corresponding preop values at 2 months postop over 3 mm zone.

Association between change in the axis of TCA (Δθt°), ACA (Δθa°) and PCA (Δθp°) with preop values

Barring for occasional outliers, Δθ° were most profound when the initial value of θ° was outside the range 70°–110°. After initial explorative analysis, subjecting the data to various permutations, linear regression revealed some significant associations between Δθ° and θ° These are listed below, the remaining associations were insignificant. At 1 month postop over 3 mm zone:

$\Delta\theta t° = 0.913\theta t° - 0.005[\theta t°]^2 + 3.049$ ($r = 0.505$, $n = 92$, $P < 0.01$), eq. 18.

$\Delta\theta a° = 0.003[\theta a°]^2 - 0.449\theta a° + 37.91$ ($r = 0.352$, $n = 92$, $P < 0.01$), eq. 19.

$\Delta\theta p° = 0.458\theta p° - 0.003[\theta p°]^2 + 10.419$ ($r = 0.225$, $n = 92$, $P = 0.031$), eq. 20.

And, over the 5 mm zone:

$\Delta\theta t° = 0.403\theta t° - 0.002[\theta t°]^2 + 25.523$ ($r = 0.221$, $n = 92$, $P = 0.034$), eq. 21.

$\Delta\theta a° = 0.003[\theta a°]^2 - 0.515\theta a° + 45.142$ ($r = 0.313$, $n = 92$, $P < 0.01$), eq. 22.

At 2 months postop over 3mm zone:

$\Delta\theta t° = 1.129\theta t° - 0.006[\theta t°]^2 - 1.813$ ($r = 0.755$, $n = 83$, $P < 0.01$), eq. 23.

$\Delta\theta p° = 1.122\theta p° - 0.006[\theta p°]^2 - 1.959$ ($r = 0.736$, $n = 83$, $P = <0.01$), eq. 24.

And, over the 5 mm zone:

$\Delta\theta t° = 0.548\theta t° - 0.003[\theta t°]^2 + 18.83$ ($r = 0.299$, $n = 83$, $P < 0.01$), eq. 25.

$\Delta\theta a° = 0.002[\theta a°]^2 - 0.444\theta a° + 42.58$ ($r = 0.278$, $n = 83$, $P = 0.011$), eq. 26.

At 3 months postop over 3mm zone:

$\Delta\theta t° = 1.391\theta t° - 0.008[\theta t°]^2 - 0.701$ ($r = 0.635$, $n = 49$, $P < 0.01$), eq. 27.

$\Delta\theta p° = 1.117\theta p° - 0.006[\theta p°]^2 + 2.035$ ($r = 0.582$, $n = 49$, $P = <0.01$), eq. 28.

And, over the 5 mm zone:

$\Delta\theta a° = 0.002[\theta a°]^2 - 0.294\theta a° + 28.704$ ($r = 0.377$, $n = 49$, $P < 0.01$), eq. 29.

The remaining associations were insignificant. Fig. 6 shows the relationship between Δθt° and θt° over 3 mm zone at 2 months postop.

Discussion

Figs. 2–5 are selected examples showing the changes in total, anterior, and PCA following routine phacoemulsification. Surgically induced changes in total corneal astigmatism (SIA) can be displayed as double angle plots.[16] In general, the double angle plots were unremarkable scattergrams except for the SIA values at 1-month postop. Fig. 2 shows the calculated SIA values were skewed towards 90° suggesting that the axis of the induced negative astigmatism leaned toward the vertical rather than the horizontal axis. All of the results rested on the algorithm for calculation of the astigmatic values. A recent publication showed that the Orbscan II was useful for checking the surgically induced astigmatism after phacotrabeculectomy.[17] Thus, there is no unequivocal reason to question the Orbscan astigmatic computations. The results show that astigmatism was more pronounced at the posterior surface. Some have reported that astigmatism at the corneal posterior surface was generally less than 0.50DC.[18-26] It has been claimed that Orbscan II tends to overestimate characteristics of the posterior corneal surface compared with other systems.[5,27] Alternatively, it could equally be argued that other systems underestimated changes at the posterior surface of the cornea.

Núñez and Blanco[28] proposed that Orbscan produced more precise results compared with Pentacam when used on normal eyes. The limits of agreement for repeat measurements of posterior corneal surface radius using Orbscan was ±0.06 mm, and this equates to less than ±0.25DC.[29] Orbscan is a reliable technique for the evaluation of the cornea and has been successfully used to refine the ablation profiles during LASIK, assess displacement of corneal surfaces after kerato-refractive procedures, monitor ectasia, and show ethnic differences in the incidence of keratoconus and monitor astigmatic changes after phacotrabeculectomy.[17,30-36]

Table 1 shows the changes in astigmatism at the posterior surface were greater compared with changes at the front surface following phacoemulsification. The magnitude of this astigmatism was lower in the central 5 mm zone compared the central 3 mm zone. By 3 months postop, over the central 3 mm optical zone there was 1.18DC change at the back but no significant change at the front. However, other reports found the opposite suggesting that the posterior corneal surface is more resilient to changes in astigmatism compared with the front surface following cataract surgery.[9,10,20,37] In addition, the total corneal astigmatism (TCA) over the central 3 mm zone increased, on average, by over 1DC by 3 months postop. This is almost twice the change in TCA reported by others.[8-12] The physical onslaught of phacoemulsification impacts directly on the corneal posterior surface. Variations in the speed and duration of ultrasound, the torrents of BSS and use of ophthalmic viscosurgical devices can affect postop endothelial cell density culminating in changes in the dynamics of fluid distribution over the cornea. Factors such as these may account for the differences between studies and scatter in Figs. 2–5.

Table 1 shows, over the central 5 mm zone small, though significant, changes in TCA and PCA occurred at 1 and 2 months postop, but the changes reduced by 3 months. Astigmatism remained stable at the anterior surface, changed significantly at the posterior surface and the latter contributed to the change in TCA. These findings do not support the results of previous investigations at 1 and 2 months postop. The lack of confluence between these results and the conclusions made by others could be related to various factors including inter-instrument differences, size of the central zone of the cornea, minutia related to different algorithms, and ethnicity.

The mean value of ACA did not change the following phacoemulsification. However, as noted in Figs. 3-5 and eqs 1–17, changes in ACA, TCA, and PCA were strongly associated with counterpart preop values. Thus, for individual cases, it is possible to predict the expected changes in TCA, ACA, and PCA. Over the 5 mm optical zone, for preop values of -1.00D for TCA, ACA, and PCA the best fit least-squares lines (eqs 9–11 predict respective changes of 1.90DC, 0.24DC, and 1.55DC after the surgery. The change in TCA appears to be driven primarily by the change in PCA not ACA. Glancing over Figs. 3 and 6, the expected changes would be negligible over the central 3 mm zone for preop TCA and PCA values of around -6DC. However, according to eqs 5, 9, 11, and 15, over the central 5 mm zone, small changes are expected for TCA and PCA values of about -4DC change. The numerical changes in both TCA and PCA alter between the two zones. This suggests that the pattern of mass distribution over the central cornea has orthogonal characteristics, the different rates of thickness change along orthogonal axes alter as we move away from the center.

Table 1 shows the mean axis value for TCA, ACA, and PCA was always about 90°. This is not unexpected when the axis of astigmatism in subjects extends over the full range from 0° through to 180°. However, changes in the axes of TCA, ACA, and PCA were to some extent associated with the preop values. The significant least-squares best fit relationships are described by eqs 18–27. These equations show the change in the axis of TCA, ACA, and PCA was more profound when the respective preop axis of astigmatism was near 90°, when the astigmatism was predominantly ‘against-the-rule’ (ATR). Fig. 6 shows the postop change in TCA axis over the central 3 mm zone is small when the preop axis falls within the 0–20° and 160–180° ranges and much higher in the 70-110° range. The postop change in axis was significantly associated with the preop axis in the central 3 mm zone but not over the 5 mm zone. This suggests, towards the center of the cornea a change in the axis of orthogonal mass distribution is most profound when the preop astigmatism is predominantly ATR. Possible reasons to account for the changes observed are purely speculative. Inadvertent eye rubbing and local variations in the efficacy of endothelial function are possibilities that cannot be ruled out. When the axis of TCA is predominantly ‘against-the-rule’ the cornea is relatively thinner at the periphery along the vertical meridian. A corneal tunnel was made at 12 o’clock in all cases. This was a deliberate intention to control and minimize the number the conflicting variables that could impact on the results. The incision in a relatively thinner, more susceptible, paracentral region may have given way to weakening of the local tissue. The ongoing pressure exerted by the eyelids and associated structures is directed primarily along the vertical direction. This pressure, in association with any local weakening of the tissue from the incision, may account for the shifts in mass distribution leading to the axis changes observed in some of cases.

Conclusion

The distribution of mass within the central region of the cornea has orthogonal characteristics. The dynamics of this distribution is affected by unremarkable phacoemulsification and remains evident up to 3 months postop. The axis of the orthogonality is more susceptible to change when the preop total corneal astigmatism is predominantly ‘against-the-rule’.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Conflicts of interest

There are no conflicts of interest.

References

1. Praeger DL, Schneider HA. Corneal thickness measurements following intraocular lens implantation. Ophthalmic Surg 1977;8:97-101.
2. Jacob JS. Corneal thickness changes following cataract surgery: Effect of lens implantation and sodium hyaluronate. Br J Ophthalmol 1985;69:567-71.
3. Vargas JM, McCulley JP, Bowman RW, Johnson WE, Jani BR, Shen J. Effect of phacoemulsification on corneal thickness. Am J Ophthalmol 2003;136:171-2.
4. Tutchenko L, Patel S, Horak O, Sanin V, Kosuba S. Effect of cataract surgery on the refractive index of the cornea estimated by optical pachymetry. Cornea 2018;37:1414-20.
5. Oliveira CM, Ribeiro C, Franco S. Corneal imaging with slit-scanning and Scheimpflug imaging techniques. Clin Exp Optom 2011;94:33–42.
6. Patel S, Marshall J, Fitzke FW. Shape and radius of posterior corneal surface. Refract Corneal Surg 1993;9:173-81.
7. Lam AK, Douthwaite WA. Measurement of posterior corneal asphericity on Hong Kong Chinese: A pilot study. Ophthalmic Physiol Opt 1997;17:348-56.
8. Hayashi K, Sato T, Yoshida M, Yoshimura K. Corneal shape changes of the total and posterior cornea after temporal versus nasal clear corneal incision cataract surgery. Br J Ophthalmol 2019;103:181-5.
9. Kim YJ, Knorz MC, Auffarth GU, Choi CY. Change in anterior and posterior curvature after cataract surgery. J Refract Surg 2016;32:754-9.
10. Nemeth G, Berta A, Szalai E, Hassan Z, Modis L. Analysis of surgically induced astigmatism on the posterior surface of the cornea. J Refract Surg 2014;30:604-8.
11. Feizi S, Delfazayebaher S, Javadi MA. Agreement between internal astigmatism and posterior corneal astigmatism in pseudophakic eyes. J Refract Surg 2018;34:379-86.
12. Kim TG, Noh SR, Jin KH. The effects of distance between the corneal apex and the inner and outer corneal wound edges on corneal astigmatism after cataract surgery. J Refract Surg 2017;33:460-8.
13. Ferreira TB, Ribeiro FJ. A novel color-LED corneal topographer to assess astigmatism in pseudophakic eyes. Clin Ophthalmol 2016;10:1521-9.
14. Patel S, Tutchenko L, Voytsekhivskyy O. An evaluation of unexpected refractive outcomes following toric IOL implantation for astigmatism: A sector subtraction graphical method for calculating the effective astigmatic correction. Arch Ukrainian Ophthalmol 2016;2:55-62.
15. Alpins N. Astigmatism analysis by the Alpins method. J Cataract Refract Surg 2001;27:31-49.
16. Abulafia A, Koch DD, Holladay JT, Wang L, Hill WE. *Editorial. Pursuing Perfection in IOL Calculations IV: Astigmatism analysis, SIA and double angleplots. J Cataract Refract Surg 2018;44:1169-74.*
17. Senthil S, Deshmukh S, Turaga K, Pesala V, Bandela PK, Ganesh J, *et al.* Surgically induced astigmatism and refractive outcomes following phacotrabeculectomy. Indian J Ophthalmol 2020;68:609-14.
18. Dunne MC, Elawad ME, Barnes DA. Measurement of astigmatism arising from the internal ocular surfaces. Acta Ophthalmol (Scand) 1996;74:14-20.
19. Seitz B, Langenbucher A, Torres F, Behrens A, Suárez E. Changes of posterior corneal astigmatism and tilt after myopic laser *in situ* keratomileusis. Cornea 2002;21:441-6.
20. Dubbelman M, Sicam VA, Van der Heijde GL. The shape of the anterior and posterior surface of the aging human cornea. Vision Res 2006;46:993-1001.
21. Jin YY, Zhou Z, Yuan XY, H, Xin Tang X. Effect of the posterior corneal surface on total corneal astigmatism in patients with age-related cataract. Int J Ophthalmol 2018;11:958-65.
22. Koch DD, Ali SF, Weikert MP, Shirayama M, Jenkins R, Wang L. Contribution of posterior corneal astigmatism to total corneal astigmatism. J Cataract Refract Surg 2012;38:2080–7.
23. Miyake T, Shimizu K, Kamiya K. Distribution of posterior corneal astigmatism according to axis orientation of anterior corneal astigmatism. PLoS One 2015;10:e0117194. doi: 10.1371/journal. pone. 0117194.
24. Klijn S, van der Sommen CM, Sicam VA, Reus NJ. Value of posterior keratometry in the assessment of surgically induced astigmatic change in cataract surgery. Acta Ophthalmol 2016;94:494-8.
25. Jiang Y, Tang Y, Jing Q, Qian D, Lu Y. Distribution of posterior corneal astigmatism and aberration before cataract surgery in Chinese patients. Eye (Lond) 2018;32:1831-8.
26. Choi Y, Eom Y, Song JS, Kim HM. Comparison of anterior, posterior, and total corneal astigmatism measured using a single Scheimpflug camera in healthy and keratoconus eyes. Korean J Ophthalmol 2010;32:163-71.
27. Byun YS, Chung SH, Park YG, Joo CK. Posterior corneal curvature assessment after epi-LASIK for myopia: Comparison of Orbscan II and Pentacam imaging. Korean J Ophthalmol 2012;26:6-9.
28. Núñez MX, Blanco C. Efficacy of Orbscan II and Pentacam topographers by a repeatability analysis when assessing elevation maps in candidates for refractive surgery. Biomédica 2009;29:362-8.
29. Martín R, Izquierdo M, de Juan V, Rodriguez G, Itziar F. Repeatability and reproducibility of Orbscan II. Optometry Rep 2012;2:e1. doi: 10.4081/optometry. 2012.e1
30. Knorz MC. Customized ablations in LASIK with TopoLink. Semin Ophthalmol 2000;15:155-9.
31. Kamiya K, Oshika T. Corneal forward shift after excimer laser kerato-refractive surgery. Semin Ophthalmol 2003;18:17-22.
32. Piñero DP. Technologies for anatomical and geometric characterization of the corneal structure and anterior segment: A review. Semin Ophthalmol 2015;30:161-70.
33. Gosavi VV, Hardten DR. Developments in diagnostic tools for corneal ectasia. Expert Review of Ophthalmology 2010;5:475-81.
34. Ramamurthy S, Reddy JC, Jhanji V. Topography and tomography in the diagnosis of corneal ectasia. Expert Rev Ophthalmol 2015;10:215-28.
35. Hashemi H, Khabazkhoob M, Fotouhi A. Topographic keratoconus is not rare in an Iranian population: The Tehran Eye Study. Ophthalmic Epidemiol 2013;20:385-91.
36. Módis L, Langenbucher A, Seitz B. Evaluation of normal corneas using the scanning-slit topography/pachymetry system. Cornea 2004;23:689-94.
37. Næser K, Savini G, Bregnhøj JF. Estimating total corneal astigmatism from anterior corneal data. Cornea 2017;36:828–33.