Surgically induced astigmatism and posterior corneal curvature changes following phacoemulsification

Khushboo Sheoran, Sudesh K Arya, Rakesh K Bansal, Jitender Jinagal, Ujjwal P Jha

Purpose: To primarily compare surgically induced astigmatism (SIA), total and posterior corneal curvature, pachymetry, and their stabilization after 2.2 and 2.8 mm clear corneal incision in phacoemulsification.

Methods: A randomized, prospective interventional study of 130 patients (130 eyes) of either sex having senile cataract (>40 years) divided randomly into two groups. The patients underwent uncomplicated phacoemulsification surgery with foldable intraocular lens implantation using 2.2 mm (group 1) and 2.8 mm incisions (group 2). The patients were evaluated preoperatively and followed-up at first, third, and sixth weeks. Results: Mean SIA was less in group 1 at all the follow-up visits which was not statistically significant (P value – 0.507 at week 1), 0.626 (at week 3), and 0.312 (at week 6). Mean SIA decreased from week 1 to week 6 in both the groups. Both the groups showed an increase in SIA with the increase in the hardness of cataract. Posterior keratometry (k1 and k2) showed statistically significant steepening in the first postoperative week, followed by gradual flattening which continued till the sixth week postoperatively. Posterior astigmatism increased in both the groups at week 1 (not statistically significant). Thereafter, it decreases and does not change significantly after 3 weeks. Pachymetry increased significantly (P value < 0.001 in both the groups) in the first week in both the groups and thereafter stabilizing at 3 weeks. Conclusion: Reducing the incision size does not result in any significant reduction in SIA. We observed that the posterior corneal curvature majorly stabilized by 3 weeks, but some stabilization continued till 6 weeks.

Key words: Clear corneal incision, phacoemulsification, posterior corneal curvature, SIA

Cataract is the leading cause of visual impairment worldwide. Surgery remains the primary treatment for age-related cataracts with an aim to achieve the best possible visual outcome. Corneal topographic changes observed after phacoemulsification are corneal steepening and flattening, occurring secondary to compression of tissue at the wound site. In order to decrease the resulting astigmatism, there is a definite trend of reducing the incision size. The reduction in incision size results in an advantage of reducing the need for suturing, leading to more wound stability and a decrease in induced corneal aberrations. These aims have created a trend toward a smaller wound from a 12.0 mm incision for intracapsular cataract extraction to a 10 mm for extracapsular cataract extraction further to 6 mm incision for small incision cataract surgery to 2.2–2.8 mm incisions in phacoemulsification.

Surgically induced astigmatism (SIA) is defined as the flattening effect in that axis induced by an incision made on the cornea and influences the refractive outcomes of cataract surgery. SIA is influenced by preoperative astigmatism, incision size, location, architecture, corneal thickness, rigidity, and wound healing postoperatively.

Previous studies have shown that smaller incision sizes help in reducing the SIA and provide better refractive outcomes. In this study, our aim is to compare and better understand the corneal topography, pachymetry changes, and SIA between 2.8 and 2.2 mm incisions among different cataract grades in phacoemulsification surgery.

Methods

Study design

This was a randomized, prospective interventional study enrolling 130 patients who were distributed randomly in group 1 (operated with 2.2 mm incision) and group 2 (operated with 2.8 mm incision) with 65 patients in each group. The study was conducted after approval from the Institutional Ethics Committee and conformed to the tenets of the Declaration of Helsinki. A written, informed consent was taken prior to enrolment.

Optimum sample size was calculated based on the mean value of astigmatism at 1 week available in the existing literature, that is, a mean of 1.32 ± 0.75 in the 2.2 mm incision group and 1.32 ± 0.72 in the 2.8 mm incision group. The confidence coefficient was further assumed to be 90%.
permissible error to be 10%, and a dropout rate of 10% during the course of follow up. Based on these assumptions, optimum sample size came out to be 130.

Participants
One-hundred thirty eyes of 130 patients of either sex having senile cataract (>40 years) graded as per Lens Opacities Classification System III (LOCS-III) grading and divided into group 1 and group 2 by a computer-generated random number table. Patients in group 1 were operated with a 2.2 mm incision and in group 2 with a 2.8 mm incision.

Exclusion criteria
Patients with preexisting conditions like pterygium grade II and III, corneal opacity, uveitis or other inflammatory eye diseases, complicated cataract, traumatic cataract, diabetic retinopathy, previous ocular surgery, and irregular astigmatism were excluded from the study.

Data collection methodology
The recruited patients were examined preoperatively and during follow-up at first, third, and sixth weeks postoperatively for uncorrected visual acuity (UCVA) and best-corrected visual acuity (BCVA) with refraction. Corneal topography and pachymetry were evaluated using anterior segment analyzer – Pentacam (Oculus, Wetzlar, Germany). Intraocular lens (IOL) power was calculated using Lenstar 900 (Haag-Streit Diagnostics, Koeniz, Switzerland). Preoperatively, +90D fundus examination and intraocular pressure measurement were done. LOCS III was used for grading the cataract.

The patients underwent uncomplicated phacoemulsification surgery with foldable IOL implantation using a 2.2 mm incision in group 1 and 2.8 mm incision in group 2 using the Oertli phacoemulsification system with the same technique. The primary outcome, SIA, was calculated using an online calculator available on doctor-hill.com at first, third, and sixth weeks postoperatively. This method of SIA calculation was described by Holladay et al. and is based on vector analysis.

Statistical analysis
Measurable values like age, sex, and LOCS III were considered qualitative or categorical variables and were described as percentages. The normality of the continuous data was tested using one Sample Kolmogorov–Smirnov test. The normally distributed data was tested using a paired t-test and the nonnormal data using Wilcoxon signed-rank test. Comparison across the two groups - with 2.2 and 2.8 mm incision - was done using Mann–Whitney’s test. The data analysis was done using the latest version 25 of IBM SPSS software (Statistical Product and Service Solutions). The reliability of different readings was done with its 95% CI and P value < 0.05 was considered to be significant.

Results
Demographic data
The patients belonged to the age group of 41–85 years with a mean age of 60.8 ± 9.5 years in group 1 and of 61.68 ± 9.9 years in group 2. There were 75 females and 55 males among the 130 patients. The majority of the patients belonged to the lower middle class (52 patients, i.e., 40%) according to Modified Kuppuswamy Scale. On analysis of symptoms at the time of presentation, 128 (98.46%) patients reported blurring of vision as the main presenting symptom, while only two patients (1.53%) had the main presenting symptom of glare. Cataract distribution in group 1 was NS I (7 patients), NS II (29 patients), NS III (18 patients), NS IV (9 patients), and NS V (2 patients). Cataract distribution in group 2 was NS I (2 patients), NS II (25 patients), NS III (25 patients), NS IV (7 patients), and NS V (6 patients). Both the groups had comparable baseline parameters and there was no significant difference between two groups in terms of age, sex, socioeconomic status, and grade of cataract.

Surgically induced astigmatism
Table 1 shows the variation of SIA in the two groups at different follow-ups. Mean SIA showed decrease from week 1 to week 6 in both the groups. The mean SIA in group 1 was lower than that in group 2 at all the follow-ups, although the difference was not statistically significant [Fig. 1]. Also, when we compared SIA between the cataract grades, both the groups showed an increase in SIA with an increase in the hardness of the cataract at all the follow-ups [Table 2]. Although group 1 did show a decrease for the NS V cataract grade but given the small sample size of NS V grade cataracts (n = 2), the observations are not representative of the grade.

Keratometry
Table 3 lists the changes in total corneal curvature [K1, K2 (steep axis), and Astigmatism (ast)] and posterior corneal curvature [k1, k2, and astigmatism (ast)]. There was no significant difference in K1 postoperatively as compared to preoperative value in both the groups at all follow-up visits [Fig. 2a-d].

Figure 1: Trends of surgically induced astigmatism

![Figure 1: Trends of surgically induced astigmatism](image-url)
Figure 2: (a) Corneal topography images of a representative patient preoperatively (b) Corneal topography images of a representative patient at 1 week follow-up (c) Corneal topography images of a representative patient at 3 weeks follow-up (d) Corneal topography images of a representative patient at 6 weeks follow-up.
K2 values showed initial steepening at week 1 and then flattening occurred which continued till week 6 postoperatively. The changes were significant at week 3 in group 2 (P = 0.003) and at week 6 in both group 1 (P = 0.001) and group 2 (P < 0.001) as compared to preoperative values within the same group [Fig. 2a-d].

Astigmatism increased at postoperative week 1 in both the groups, though the change was not statistically significant. Thereafter, astigmatism decreased till week 6. The change was significant in group 1 at week 6 (P = 0.038) and in group 2 at week 3 (P = 0.001) and week 6 (P < 0.001).

Table 1: Mean surgically induced astigmatism (SIA)

| Parameter | Property | Week 1 | Week 3 | Week 6 | p value |
|-----------|----------|--------|--------|--------|---------|
| SIA       |          |        |        |        |         |
| Group 1   | Mean±SD  | 0.61±0.32 | 0.56±0.3 | 0.46±0.24 |         |
| Group 2   | Mean±SD  | 0.66±0.44 | 0.59±0.4 | 0.5±0.28  | 0.507   |
|           | p value  | 0.626   | 0.312   |         |         |

Table 2: Comparison of preoperative and postoperative total and posterior corneal curvature

| LOCS-III Grade | Parameter | Property | Pre-Operative | Week 1 | Week 3 | Week 6 |
|----------------|-----------|----------|---------------|--------|--------|--------|
| NS I           | K1        | Mean±SD  | 43.35±1.82    | 43.31±1.81 | 43.32±1.75 | 43.28±1.77 |
|                | p         |          | 0.743         | 0.781   | 0.214  |         |
|                | Group 2   | Mean±SD  | 43.78±1.95    | 43.75±1.91 | 43.81±1.99 | 43.83±1.91 |
|                | p         |          | 0.317         | 0.709   | 0.340  |         |
| NS II          | K2        | Mean±SD  | 44.01±1.79    | 44.04±1.83 | 43.96±1.75 | 43.84±1.76 |
|                | p         |          | 0.693         | 0.280   | 0.001  |         |
|                | Group 2   | Mean±SD  | 44.68±1.93    | 44.7±1.89 | 44.54±1.94 | 44.46±1.88 |
|                | p         |          | 0.842         | 0.003   | < 0.001|         |
| NS III         | AST       | Mean±SD  | 0.66±0.49     | 0.73±0.49 | 0.64±0.45 | 0.55±0.37 |
|                | p         |          | 0.121         | 0.676   | 0.038  |         |
|                | Group 2   | Mean±SD  | 0.89±0.42     | 0.96±0.4 | 0.73±0.38 | 0.63±0.36 |
|                | p         |          | 0.072         | 0.001   | < 0.001|         |
| NS IV          | k1        | Mean±SD  | -6.14±0.44    | -6.19±0.42 | -6.16±0.43 | -6.15±0.43 |
|                | p         |          | 0.015         | 0.484   | 0.342  |         |
|                | Group 2   | Mean±SD  | -6.17±0.35    | -6.21±0.36 | -6.2±0.33 | -6.19±0.33 |
|                | p         |          | 0.038         | 0.116   | 0.141  |         |
| NS V           | k2        | Mean±SD  | -6.47±0.48    | -6.55±0.49 | -6.47±0.47 | -6.46±0.47 |
|                | p         |          | 0.020         | 0.898   | 0.680  |         |
|                | Group 2   | Mean±SD  | -6.5±0.35     | -6.57±0.34 | -6.52±0.33 | -6.5±0.31 |
|                | p         |          | 0.007         | 0.145   | 0.901  |         |
|                | ast       | Mean±SD  | -0.33±0.19    | -0.36±0.22 | -0.31±0.2 | -0.31±0.25 |
|                | p         |          | 0.138         | 0.338   | 0.360  |         |
|                | Group 2   | Mean±SD  | -0.33±0.19    | -0.36±0.17 | -0.32±0.16 | -0.31±0.13 |
|                | p         |          | 0.124         | 0.676   | 0.336  |         |

Pachymetry

Pachymetry differed significantly over the first week in both the groups when it increased due to corneal edema. It decreased thereafter stabilizing at 3 weeks [Table 4 and Fig. 2a-d].
The change in pachymetry values at week 1 with respect to preoperative levels was higher in group 2 patients than in group 1 patients, although the difference was not statistically significant. We also observed that the harder cataracts led to more corneal edema postoperatively at week 1 [Table 5]. The higher increase in corneal thickness in group 2 can be attributed to unequal distribution of patients in different cataract grades between the two groups as there were a greater number of hard cataracts in group 2.

Visual acuity
Visual acuity findings are summarized in Table 4. There was a significant improvement in both the groups at all follow-up visits.

Discussion
Phacoemulsification surgery with IOL implantation has become one of the safest, consistent and frequently performed surgery in ophthalmic practice leading to significant visual improvement. Any incision on cornea can potentially alter the optical power of the cornea. Reducing the incision size results in reducing the need for suturing, leading to more wound stability and a decrease in corneal aberrations.[7]

In this study, 130 patients were evaluated pre- and postphacoemulsification surgery in two groups with 2.2 mm incision and 2.8 mm incision, respectively (65 patients in each group). Phacoemulsification surgery led to significant improvement in UCVA and BCVA in both the groups at all follow-up visits. Similar trends were seen in a study by Hashemi et al.,[10] showing significant improvement in UCVA and BCVA in the postoperative period.

Surgically induced astigmatism
SIA can be calculated by different methods. In this study, SIA was calculated using an online calculator available on doctor-hill.com on all follow-up visits. The mean SIA in group 1 was lower than that in group 2 at all the follow-ups, although the difference was not statistically significant [Table 1]. In both the groups, the mean SIA decreased in the further follow-ups which could be due to higher edema in the first postoperative week (responsible for the steepening effect at week 1), which starts resolving thereafter [Fig. 1]. Also, when we compared SIA between the cataract grades, both the groups showed an increase in SIA with an increase in the hardness of the cataract at all the follow-ups. Although group 1 did show a decrease for the NS V cataract grade, given the small sample size of NS V grade cataracts (n = 2), the observations are not representative of the grade.

Hashemi et al.,[10] in a study compared 2.2 and 2.8 mm incision groups by using vectoral analysis for SIA. They concluded that there were no clinical or statistically significant differences between the two techniques in minimizing the effect of incision size on SIA ($P$ value 0.479). This was similar to findings observed in our study.

Corneal topography and keratometry
$K_1$ for both the groups did not show any significant change in the postoperative period at all the follow-ups within the group. $K_1$ values got stabilized around the preoperative values at the third postoperative week [Fig. 2a-d].
K2 (steeper axis) values showed initial steepening at week 1 and then flattening occurred which continued till week 6. The changes were significant at week 3 in group 2 ($P = 0.003$) and at week 6 in both group 1 ($P = 0.001$) and group 2 ($P < 0.001$) as compared to preoperative values within the same group [Fig. 2a-d]. A study by Tetikoglu M et al. [11] with mean preoperative K values of 43.7 ± 1.53 D for 2.0 mm incision group and 43.67 ± 1.72 D for the 2.8 mm incision group also showed a similar stabilization behavior. These values got stabilized around preoperative values (43.7 ± 1.54 D for 2.0 mm incision and 43.7 ± 1.84 D for 2.8 mm incision) at 1 month postoperatively.

AST in both the groups showed an increase at week 1 and thereafter it decreased up to sixth postoperative week. The change was significant in group 1 at week 6 ($P = 0.038$) and in group 2 at week 3 ($P = 0.001$) and week 6 ($P < 0.001$). In a study by Park Y et al. [5] comparing the torsional and flattening effect of 2.2 and 2.85 mm clear corneal incisions, a similar behavior was observed where there was no significant change in total corneal astigmatism at day 1 postoperatively, but changes were significant at 1 and 2 months. However, a study by Sethi et al. [7] where compared phacoemulsification with 2.2 and 2.8 mm incision groups and found that there is a steady decrease in postoperative astigmatism and there were no statistically significant differences between the two groups.

Posterior curvature (k1, k2, and ast)
Both the groups showed similar trends for k1 and k2. There was statistically significant steepening in the first postoperative week [Table 2]. This was followed by

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**Table 4: Comparison of preoperative and postoperative Pachymetry, UCVA, Spherical Equivalent (SE), and BCVA**

| Parameter       | Group 1 | Property | Preoperative | Week 1   | Week 3   | Week 6   |
|-----------------|---------|----------|--------------|----------|----------|----------|
| Pachymetry      | Mean±SD |          | 511.35±39.38 | 553.14±42.17 | 513.63±38.88 | 512.34±36.82 |
|                 | p       |          | < 0.001 | 0.078 | 0.138 |
| Group 2         | Mean±SD |          | 517.37±38.06 | 563.6±40.86 | 520.71±36.58 | 517.06±35.51 |
|                 | p       |          | < 0.001 | 0.108 | 0.967 |
| UCVA            | Group 1 | Mean±SD | 0.91±0.39 | 0.35±0.26 | 0.21±0.23 | 0.18±0.19 |
|                 | p       |          | < 0.001 | < 0.001 | < 0.001 |
| Group 2         | Mean±SD |          | 0.98±0.36 | 0.51±0.25 | 0.3±0.17 | 0.26±0.17 |
|                 | p       |          | < 0.001 | < 0.001 | < 0.001 |
| SE              | Group 1 | Mean±SD | -0.29±0.99 | -0.18±0.51 | -0.16±0.51 | -0.16±0.49 |
|                 | p       |          | 0.354 | 0.321 | 0.315 |
| Group 2         | Mean±SD |          | -0.32±1.66 | -0.3±0.92 | -0.26±0.69 | -0.26±0.61 |
|                 | p       |          | 0.937 | 0.793 | 0.765 |
| BCVA            | Group 1 | Mean±SD | 0.7±0.36 | 0.16±0.21 | 0.07±0.13 | 0.05±0.12 |
|                 | p       |          | < 0.001 | < 0.001 | < 0.001 |
| Group 2         | Mean±SD |          | 0.72±0.33 | 0.3±0.25 | 0.07±0.11 | 0.05±0.09 |
|                 | p       |          | < 0.001 | < 0.001 | < 0.001 |

**Table 5: Comparison of pachymetry change (preoperative - Week 1)**

| Parameter       | Group 1 | Property | Cataract grade | NS I | NS II | NS III | NS IV | NS V |
|-----------------|---------|----------|----------------|------|-------|--------|-------|------|
| Pachymetry change (Pre-Op - Week 1) | Mean of change | | | 29 | 39.07 | 45.11 | 49.33 | 62 |
| Group 2 | Mean of change | | | 29.5 | 41.32 | 45.12 | 54.43 | 67.5 |
gradual flattening, which continued till the sixth week postoperatively [Figs. 2a-d, 3 and 4].

In our study, posterior astigmatism increased in both the groups at week 1, although the difference was not statistically significant. Thereafter, it decreases and does not change significantly after 3 weeks [Fig. 5]. In a study by Schmitt AJ et al.,[12] with 2.75 mm corneal incision where they have studied posterior corneal curvature changes, similar focal steepening was seen in both k1 and k2. These changes returned to preoperative values by 3 months and the differences were not statistically significant at any postoperative visit. In another study by Hayashi et al.,[13] similar findings were observed. It was found that a focal steepening occurred in the posterior cornea around both the nasal and temporal CCI s of 2.4 mm and this wound-related steepening rapidly diminished and was not detected at 4 weeks after surgery or later in either group.

Pachymetry
Pachymetry values differed significantly over the first week as they increased due to corneal edema and gradually decreased thereafter. In both the groups, the mean pachymetry values stabilized around the preoperative value by the third postoperative week. Although the change in pachymetry values at week 1 with respect to preoperative levels was higher in group 2 patients than the group 1 patients, the difference was not statistically significant (P = 0.18). Since we observed that the harder cataracts lead to more corneal edema postoperatively at week 1, the higher increase in corneal thickness in group 2 can be attributed to unequal distribution of patients in different cataract grades between the two groups as there were a greater number of hard cataracts in group 2. This was in contrast with findings of Sethi et al.[14] in which 2.2 mm incision group had higher increase in corneal thickness postoperatively as compared to the 2.8 mm incision group. In a study by Chaudhry et al.,[15] it was found that pachymetry returned to normal baseline values in 1-month time with no statistically significant difference between preoperative and postoperative values at 1 month.

A potential limitation of the present study is the relatively short duration of follow-up. Since certain parameters stabilization continued till 6 weeks, it might be useful to look at these parameters with larger follow-up duration. Also, the unequal grade-wise distribution led to certain cataract grades having less number of patients. A study with potentially larger numbers of patients can help in statistically characterizing grade-level differences between the two groups.

Conclusion
We found out that 2.2 mm incision induced a lesser amount of SIA as compared to 2.8 mm incision, although the difference was not statistically significant at all the follow-up visits. Thus, reducing the incision size from 2.8 to 2.2 mm does not have a significant effect on SIA. We also observed that posterior curvature changes get stabilized majorly by 3 weeks postoperatively, but some stabilization continued till 6 weeks.

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Conflicts of interest
There are no conflicts of interest.

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