Original Article

# Analysis of photoastigmatic keratectomy with the cross-cylinder ablation

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**Aim:** The aim was to evaluate the safety and efficacy of the "cross-cylinder" technique in the correction of astigmatism. **Setting and Design:** A prospective interventional study from a university eye department was conducted. **Material and Methods:** The photoastigmatic refractive keratectomy (PARK) using the "cross-cylinder" technique was performed in 102 eyes of 84 patients with at least 0.75 D of astigmatism. The study population was divided into two groups: in the first group the preoperative astigmatic power ranged from −0.75 D to −3.00 D (group 1), in the second group it ranged from −3.25 D to −6.00 D (group 2). Group 1 included 82 eyes of 67 patients (29 males and 38 females) with a mean cylinder power of −1.90 ± 0.63 D, group 2 included 20 eyes of 17 patients (13 males and 4 females) with a mean cylinder power of -4.28 ± 0.76 D. All eyes were targeted for emmetropia. The results were evaluated using Calossi's vector analysis method. Six-month postoperative outcomes are presented. **Results:** Six months after PARK the mean sphere for the entire cohort was +0.28 ± 0.75 D (range +2.5 to −2 D), the mean cylindrical power was +0.33 ± 0.51 D (range +2.5 to −1.25 D) and the mean spherical equivalent refraction was +0.73 ± 0.81 D (range +1.75 to −2 D). **Conclusions:** The cross-cylinder technique may be safely used with predictable results for the correction of astigmatism.

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The safety and efficacy of photorefractive keratectomy (PRK) for the surgical correction of low to moderate myopia have been well established.[1-3]

Although the refractive outcomes for low myopia have been excellent, PRK for the correction of hyperopia and astigmatism has not been as favorable.[4,5]

In particular, several side effects such as corneal haze and halos have been associated with correction of astigmatism using photoastigmatic refractive keratectomy (PARK) using toric ablations.[5] It has proposed that these side effects are due to the use of toric ablations that use differing treatment zones in the flat and steep meridians to correct astigmatism.[6] To reduce the chances of halos and other side effects, the use of combined ablations along the steep and flat meridians to correct astigmatism has been advocated.[7-9] By combining ablation along the flat and steep meridians, the multiple refractive gradient created on the cornea by a toric ablation is obviated.

Vinciguerra and colleagues (1999) introduced one such method called the "cross-cylinder" technique.[6] In the cross-cylinder technique, astigmatism is treated by splitting the correction over the steep and flat meridians. To our knowledge there is a paucity of papers reporting the use of this technique and those that exist report outcomes on a small number of patients.[9-14] In an effort to add to the current body of literature on the cross-cylinder technique, the present study evaluates refractive outcomes using this technique for the correction of astigmatism. The outcomes are reported utilizing a method described by Calossi and colleagues who proposed a simple program written in beginner's all-purpose symbolic instruction code (BASIC) computer language that can be easily adapted to any personal computer or programmable calculator.[15]

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## Materials and Methods

### Patient Population and Baseline Examinations

This was a prospective study in which 102 eyes of 84 patients with at least 0.75 diopters of astigmatism underwent PARK using the cross-cylinder technique. All patients included in the study were 18 years of age or older. The study population was divided into two groups based on preoperative astigmatism; the first group (group 1) had preoperative astigmatism ranging from −0.75 D to −3.00 D, the second group (group 2) had preoperative astigmatism that ranged from −3.25 D to −6.00 D. Group 1 included 82 eyes of 67 patients (29 males and 38 females) with a mean cylinder power of −1.90 D ± 0.63 D. The mean age of the group 1 cohort was 34.1 ± 9.63 years (range: D 18 to 56 years). Group 2 included 20 eyes of 17 patients (13 males and 4 females) with a mean cylinder power −4.28 D ± 0.76 D. The mean age of the group 2 cohort was 32.2 ± 11.23 years (range: 20 to 45 years) with no statistical difference (*P*=0.55).

Patients were asked to discontinue wearing hard or soft contact lenses for at least 1 month prior to undergoing the last refractive evaluation, which was performed the day the patient underwent PARK. Patients with systemic and ocular diseases which could interfere with corneal wound healing or with the refractive outcome, such as diabetes, corneal dystrophies, collagenopathies, dry eyes, uveitis, corneal, and lens opacities and glaucoma were excluded from the study. Baseline examination included distance-uncorrected visual acuity (UCVA) and best spectacle corrected visual acuity (BSCVA), manifest refraction (MR), slit lamp examination, and dilated fundus examination.

One, 3, and 6 months after treatment, all the patients underwent a complete ophthalmic examination as stated above, excluding dilated fundus examination.

### Surgeries

The treatment of sphere and cylinder were performed by combining objective and subjective refractions to achieve the best corrected visual acuity (BCVA), i.e., in case the objective refraction did not reach a 10/10 BCVA, we looked for the subjective refraction with a red-green test that allowed us to reach such result. In the case of discrepancy between keratometric and subjective (clinical) cylinder power and axis, the subjective cylinder power and axis were used in the treatment plan.

All eyes that underwent surgery had one or two drops of oxybuprocaine instilled prior to insertion of a lid speculum. The epithelial layer removal was carried out using a mechanical brush. The area of denuded epithelium was large enough to accommodate the transition zone ablation. Correct alignment of the eye with the laser was achieved by aligning the microscope reticule cross hairs and the first Purkinje image of the red diode laser alignment beam. Particular care was taken in positioning the patient's head before starting the treatment, and in keeping the head and neck axis parallel to axial length of the patient's body and the laser system bed. The cylinder axis was not marked preoperatively on the peripheral cornea as it has been deemed unnecessary.[16] The patient was required to fixate on a red fixation light that was coaxial with the surgeons' line of sight and excimer laser beam. All ablations were performed using the NIDEK EC-5000 excimer laser (NIDEK Co. Ltd., Gamagori, Japan) which used an expanding diaphragm and rotating scanning slit delivery system. The cross-cylinder ablation technique as described by Vinciguerra and colleagues was used.[6] Using this technique, half the power of the cylinder was ablated along the steep meridian, then the remaining cylinder was ablated along the flat meridian, subsequently the correction of the spherical equivalent was performed. All eyes were targeted for emmetropia.

After the refractive correction, smoothing of the stromal surface was performed using the phototherapeutic keratectomy mode (PTK) of the laser in conjunction with 0.04% hyaluronic acid. Immediately following surgery, a bandage contact lens was placed on the cornea and removed after complete reepithelialization that occurred after a mean period of 5 days, with no difference between the two groups. Patients received diclofenac sodium 0.1% eye drops to use twice a day for the first 2 days, nethilmicin preservative-free eye drops four times a days until reepithelialization and preservative-free artificial tears as needed for 1 month. After reepithelialization, clobetasone eye drops were prescribed to all patients to use for 1 month on a tapered schedule, as follows: one drop four times a day for the first week, one drop three times a day for the second week, one drop twice a day for the third week, and one drop once a day for the last week.

### Data Analysis

Astigmatism analysis was performed according to the method described by Calossi.[15] Several methods can be used to make this evaluation. The mathematical approach requires tedious trigonometric calculation. There are diagrams that obviate this inconvenience and allow calculation using graphical methods. An alternative method is to use prepared tables. With a programmable calculator or personal computer, however, the calculation is significantly faster and accurate. Holladay *et al.*[17] have proposed a program for the Texas Instruments Model TI 59 calculator. Calossi proposed a simple program written in BASIC computer language that with minimum modifications may be easily adapted to any personal computer or programmable calculator.

The chosen formulas for calculating the obliquely crossed cylinders solution are the ones described by Bennett and Blumlein.[18]

$$C = \sqrt{(F_1 + F_2)^2 - 4F_1F_2\sin^2\alpha}$$

$$\tan\theta = \frac{F_2 - F_1 + C}{F_1 + F_2 + C}\tan\alpha$$

$$ax = ax_{F_1} + \theta$$

$$S = \frac{F_1 + F_2 - C}{2}$$

where $F_1$ and $F_2$ are the powers of the two cylinders;
$\alpha$ is the angle between the axes of the two cylinders;
S is the value of the resulting sphere;
C is the value of the resulting cylinder;
$\theta$ is the angle between the axes of the resulting cylinder and $F_1$;
ax is the axes of the resulting cylinder;
$ax_{F1}$ is the axis of $F_1$.

In these formulas choosing $F_1$ and $F_2$ is based on the fact that the angle $\alpha$ between the two cylinders must be acute, taken to be positive and measured in a counter clockwise direction from $F_1$ to $F_2$. This condition determines the choice of $F_1$. The program automatically identifies $F_1$ and $F_2$; hence, the two sphero-cylinders to be resolved may be inserted in any order and in any combination (plus or minus cylinder).

## Results

The mean preoperative spherical power for the entire study population was −4.7 ± 3.55 D (range: +3.5 D to −14 D), the mean cylindrical power was −2.26 ± 1.30 D (range: −1 to −6 D) and the mean spherical equivalent refraction was −5.84 ± 3.36D (range: −1 to −14.75 D).

The mean postoperative sphere for the entire study population was −1.03 ± 0.91D D (range: +3.5 to −0.75D) at 1 month, −0.94 ± 0.80D (range: +3 to −0.5 D) at 3 months and +0.69 ± 0.76D (range: +2.5 to −2 D) at 6 months. The mean postoperative cylinder power for the entire study population was 0.37 ± 0.68 D (range: +2.5 to −1.75 D) at 1 month, +0.30 ± 0.63 D (range: +2.5 to 2 D) at 3 months and +0.33 ± 0.51 D (range: +2.5 to −1.25 D) at 6 months. The mean postoperative spherical equivalent refraction for the entire study population was +1.12 ± 1.01 D (range: +3.37 to −1.62 D) at 1 month, +1 ± 0.91D (range: +3.75 to -0.87D) at 3 months and +0.73 ± 0.81 D (range: +1.75 to −2D) at 6 months. The correlations between attempted and achieved corrections as spherical equivalent and cylinders are shown in Figures 1-6.

The effective refractive corrections using Calossi's

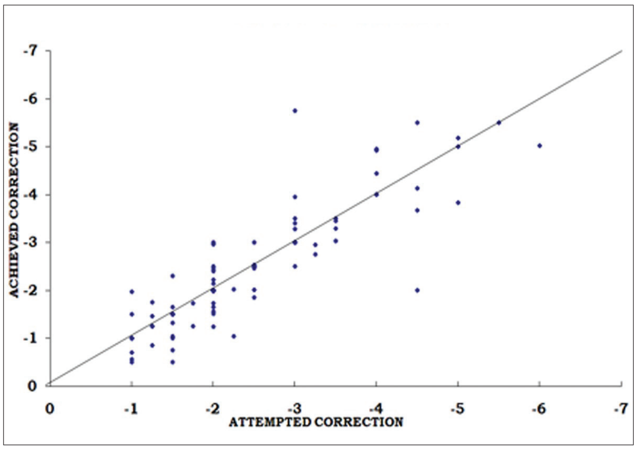


**Figure 1:** Scatter plot between attempted and achieved correction as cylinder at 1 month

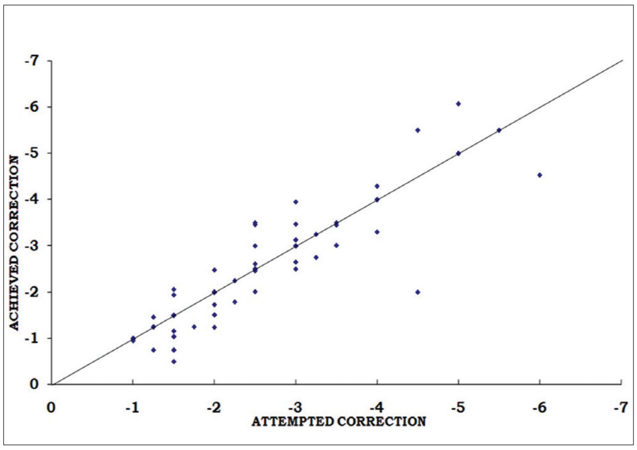


**Figure 2:** Scatter plot between attempted and achieved correction as cylinder at 3 months

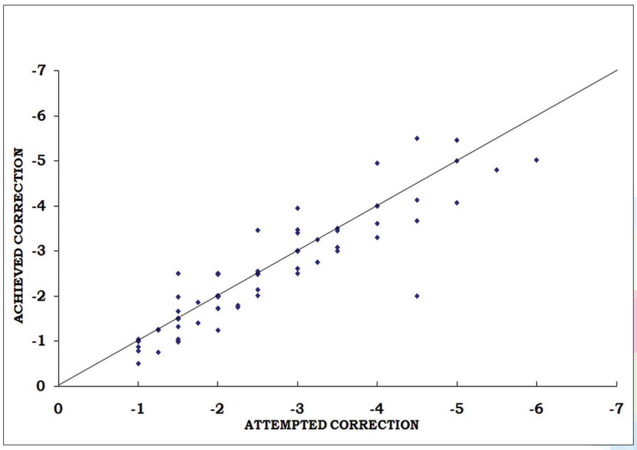


**Figure 3:** Scatter plot between attempted and achieved correction as cylinder at 6 months

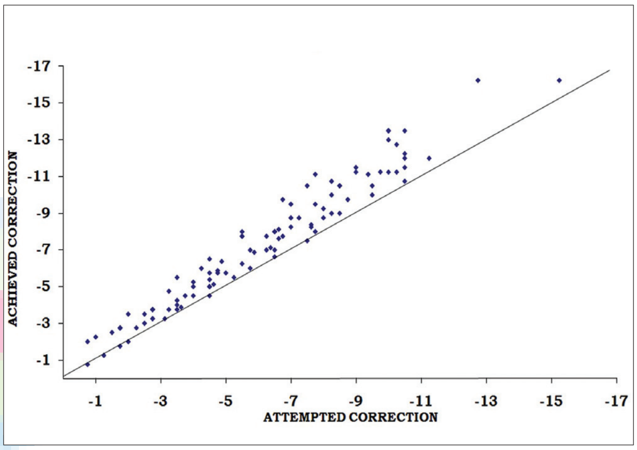


**Figure 4:** Scatter plot between attempted and achieved correction as spherical equivalent at 1 month

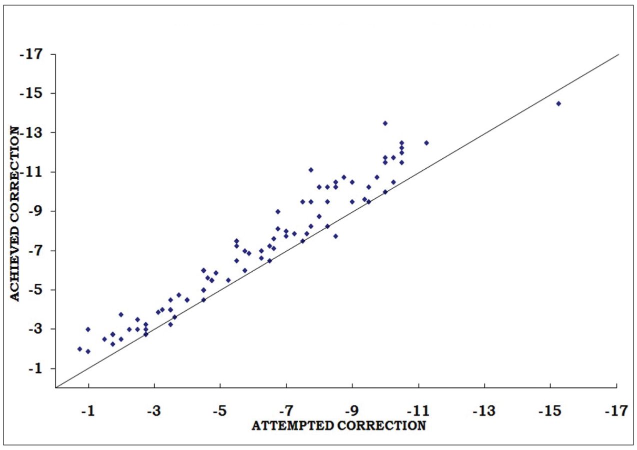


**Figure 5:** Scatter plot between attempted and achieved correction as spherical equivalent at 3 months

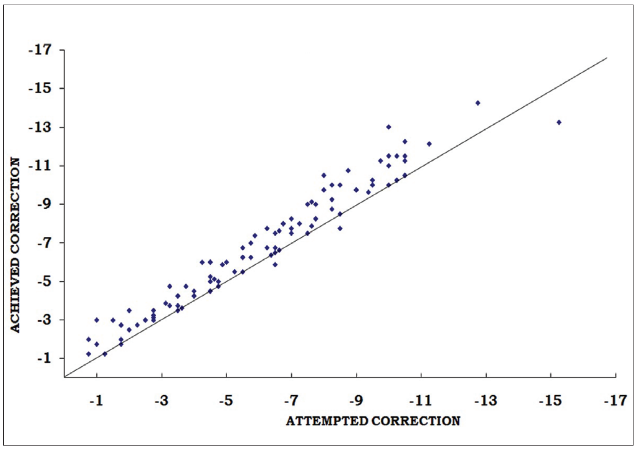


**Figure 6:** Scatter plot between attempted and achieved correction as spherical equivalent at 6 months

calculation are shown in Table 1. The safety and predictability of the treatment are shown in Table 2 and Figure 7. The UCVA and BCVA before and after treatment are shown in Table 3.

## Discussion

In this study of PARK using the cross-cylinder technique for the

**Table 1: Spherical and astigmatic defect preop (in diopters) and the correction achieved after 1, 3 and 6 months from refractive surgery in groups 1 and 2**

| | Preop | | 1 month | | | 3 months | | | 6 months | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | P | Mean | SD | P | Mean | SD | P |
| Group 1 (cyl −0.75 to −3.00) | | | | | | | | | | | |
| SphEq | −6.59 | ±2.83 | −7.85 | ±3.31 | <0.001 | −7.85 | ±3.00 | <0.001 | −7.27 | ±2.93 | <0.001 |
| Cyl | −1.90 | ±0.63 | −1.92 | ±0.87 | 0.701 | −1.85 | ±0.78 | 0.375 | −1.89 | ±0.73 | 0.775 |
| Group 2 (cyl −3.25 to −6.00) | | | | | | | | | | | |
| Sph Eq | −3.95 | ±3.58 | −4.90 | ±4.50 | <0.001 | −5.48 | ±4.47 | <0.001 | −5.06 | ±4.17 | <0.001 |
| Cyl | −4.28 | ±0.76 | −4.04 | ±0.96 | 0.292 | −4.18 | ±1.19 | 0.342 | −4.0 | ±0.98 | 0.07 |

**Table 2: Percentage of improvement and decreasing of uncorrected visual acuity and best correct visual acuity after 6 months in groups 1 and 2**

| | UCVA (%) | BCVA (%) |
|---|---|---|
| Group 1 (cyl −0.75, −3.00) | | |
| Improvement | 80 (97.5) | 60 (73) |
| Unchanged | | 18 (22) |
| Decreased | 2 (2.5) | 4 (5) |
| Group 2 (cyl −3.25, −6.00) | | |
| Improvement | 16 (80) | 14 (70) |
| Unchanged | | 2 (10) |
| Decreased | 4 (20) | 4 (20) |

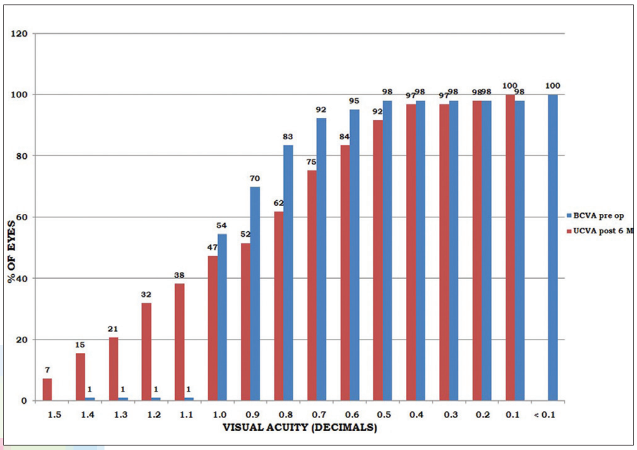


**Figure 7:** Graphics of cumulative visual acuity 6 months after surgery

**Table 3: Uncorrected visual acuity and best correct visual acuity preop and after 1, 3, and 6 months from refractive surgery in groups 1 and 2**

| | Preop | | 1 month | | 3 months | | 6 months | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Group 1 (cyl −0.75, −3.00) | | | | | | | | |
| UCVA | 0.07 | ±0.06 | 0.77 | ±0.37 | 0.88 | ±0.36 | 0.98 | ±0.27 |
| BCVA | 0.90 | ±0.16 | 1.03 | ±0.26 | −1.08 | ±0.25 | 1.65 | ±2.42 |
| Group 2 (cyl −3.25, 6.00) | | | | | | | | |
| UCVA | 0.12 | ±0.08 | 0.68 | ±0.33 | 0.75 | ±0.34 | 0.75 | ±0.31 |
| BCVA | 0.89 | ±0.17 | 0.95 | ±0.25 | 1.03 | ±0.19 | 0.99 | ±0.21 |

correction of astigmatism, we found satisfactory outcomes in patients with preoperative astigmatism up to 3.00 D (group 1). In this group of patients, the visual outcomes were acceptable with only 2.5% of eyes losing UCVA and 5% of eyes losing BCVA. However the cross-cylinder technique was not as successful in the group 2 patients who have had astigmatism up to 6 D. In group 2 eyes, 20% of the eyes lost UCVA and 20% of the eyes lost BSCVA; however the number of eyes treated was quite small (only 20 eyes) and perhaps a larger patient sample may yield different results.

A number of surgical techniques have been developed to correct astigmatism, such as relaxing incisions[19] (radial, transverse, and arcuate), trapezoidal astigmatic keratotomy,[20] and wedge resections.[21] The number and variety of these methods are due to the lack of success of any one of these approaches to predictably eliminate corneal cylinder in all cases. Excimer laser ablation for the correction of astigmatism has been used with several techniques such as, transverse keratectomy,[22] toric ablations utilizing erodible masks,[23] rotatory masks,[24,25] slit masks,[26] and elliptical optical zones.[27]

Comparison of the results of this study to similar ones in the peer reviewed literature is not a simple task due to a lack of consistency in the method of analysis. Some papers do not evaluate outcomes using vector analysis, and others use entirely different methods of analysis.

While the evaluation of the results for spherical correction such as myopia and hyperopia is quite simple, the evaluation of the astigmatic data are much more complex, as both the change in power and axis has to be analyzed. Postoperatively, there may be changes in the spherical and the cylindrical components of the ametropia. In astigmatism, there may be variations in both the power and the axis that must be documented. The best way to describe change in astigmatism caused by surgery is by vectorial analysis, which indicates the changes in power and the axis. However, in clinical practice, this procedure is limited by the tedious calculations required to establish the oblique cylinder combinations. To solve this problem several methods have been described.[16,28-32] All of them seem to be very good, and it is difficult to establish which one is more reliable; however some of them are quite difficult to utilize, require difficult calculations, and sometimes are difficult to interpret. The advantage of the method described by Calossi is that he proposed a simple computer program using vectorial analysis, of the refractive changes induced by surgery that can be used even by people that do not have deep mathematical skills. The program allows reference to refractive data or keratometric readings. In the case of refractive data, it is also possible to obtain the transposition of the correction values from the spectacle plane to that of the cornea. Additionally, the program enables the user to calculate the coupling ratio. Due to the lack of consistency in presenting the outcomes of astigmatism treatment after refractive surgery, we recommend using Calossi's method as a simple and accurate method of evaluating the results of refractive and corneal surgery.

Although a more extensive double-blind study comparing the variety of methods used to treat astigmatism may be warranted, we found the cross-cylinder technique safe and effective in correcting low to moderate astigmatism.

## References


1. Tole DM, McCarty DJ, Couper T, Taylor HR. Comparison of laser *in situ* keratomileusis and photorefractive keratectomy for the correction of myopia of -6.00 diopters or less. Melbourne Excimer Laser Group. J Refract Surg 2001;17:46-54.
2. Pop M, Payette Y. Results of bilateral photorefractive keratectomy. Ophthalmology 2000;107:472-9.
3. Pop M, Payette Y. Photorefractive keratectomy versus laser *in situ* keratomileusis: A control-matched study. Ophthalmology 2000;107:251-7.
4. Dausch D, Smecka Z, Klein R, Schröder E, Kirchner S. Excimer laser photorefractive keratectomy for hyperopia. J Cataract Refract Surg 1997;23:169-76.
5. El-Agha MS, Bowman RW, Cavanagh D, McCulley JP. Comparison of photorefractive keratectomy and laser *in situ* keratomileusis for the treatment of compound hyperopic astigmatism. J Cataract Refract Surg 2003;29:900-7.
6. Vinciguerra P, Sborgia M, Epstein D, Azzolini M, MacRae S. Photorefractive keratectomy to correct myopic or hyperopic astigmatism with a cross cylinder ablation. J Refract Surg 1999;15 Suppl 2:S183-5.
7. Molina R, Monasterio R, Soliz E, Foianini J. Correction of astigmatism using positive and negative cylinder programs with the Nidek EC 5000 excimer laser. J Refract Surg 1999;15 Suppl 2:195-6.
8. Chayet A, Magallanes R, Montes M, Chavez S, Robledo N. Laser *in situ* keratomileusis for simple myopic, mixed, and simple hyperopic astigmatism. J Refract Surg 1998;14 Suppl 2:175-6.
9. Bharti S, Bharti R, Samantaray D. Comparison of cross cylinder ablation using the optimized ablation transition zone and the torsion error detector for correction of astigmatism. J Refract Surg 2004;20 Suppl 5:663-5.
10. Shin SJ, Lee HY. The efficacy of multi-zone cross-cylinder method for astigmatism correction. Korean J Ophthalmol 2004;18:29-34.
11. Hassaballa MA, Ayala MJ, Alio JL. Laser *in situ* keratomileusis correction of mixed astigmatism by bitoric ablation. J Cataract Refract Surg 2003;29:1889-95.
12. Chayet AS, Montes M, Gòmez L, Rodríguez X, Robledo N, MacRae S. Bitoric *in situ* keratomileusis for the correction of simple myopic and mixed astigmatism. Ophthalmology 2001;108:303-8.
13. Azar DT, Jonathan DP. Theoretical analysis of ablation depths and profiles in laser *in situ* keratomileusis for compound hyperopic and mixed astigmatism. J Cataract Refract Surg 2000;26:1123-36.
14. Sheludchenko VM, Fadeykina T. Comparative results between standard and bitoric nomograms for astigmatism correction. J Refract Surg 2001;17 Suppl 2:238-41.
15. Calossi A, Verzella F, Penso A. Computer program to calculate vectorial change of refraction induced by refractive surgery. Refract Corneal Surg 1993;9:276-82.
16. Huang D, Stulting RD, Carr JD, Thompson KP, Waring GO 3rd. Multiple regression and vector analysis of laser *in situ* keratomileusis for myopia and astigmatism. J Refract Surg 1999;15:538-49.
17. Holladay JT, Gruber AJ, Lewis JW. Refining toric soft contact lens prescriptions. CLAO J 1984;10:326-31.
18. Bennett AG, Blumlein SJ. Ophthalmic Prescription Work. 2nd ed. London: Butterworth; 1983. p. 149-51.
19. Troutman RC, Swinger C. Relaxing incision for control of postoperative astigmatism following keratoplasty. Ophthalmic Surg 1980;11:117-20.
20. Villaseñor RA, Stimac GR. Clinical results and complications of trapezoidal keratotomy. J Refract Surg 1988;4:125-31.
21. Troutman RC. Corneal wedge resections and relaxing incisions for postkeratoplasty astigmatism. Int Ophthalmol Clin 1983;23:161-8.
22. Schipper I, Suppelt C, Senn P. Correction of astigmatism with excimer laser transverse keratectomy. Acta Ophthalmol 1994;72:39-42.
23. Eggink CA, de Boo TM, Lemmens AJ, Deutman AF. Photorefractive keratectomy with an ablatable mask for myopic astigmatism. J Refract Surg 1999;15:550-5.
24. Nagy ZZ, Krueger RR, Suveges I. Photorefractive keratectomy for astigmatism with the Meditec MEL 60 laser. J Refract Surg 2001;17:441-53.
25. Dausch DG, Klein RJ, Schroder E, Schröder E, Niemczyk S. Photorefractive keratectomy for hyperopic and mixed astigmatism. J Refract Surg 1996;12:684-92.
26. McDonnell PJ, Moreira H, Clapham TN, D'Arcy J, Munnerlyn CR. Photorefractive keratectomy for astigmatism. Initial clinical results. Arch Ophthalmol 1991;109:1370-3.
27. Shah S, Smith RJ, Pieger S, Chatterjee A. Effect of an Elliptical optical zone on outcome of photoastigmatic refractive keratectomy. J Refract Surg 1999;15 Suppl 2:188-91.
28. Alpins N. Astigmatic analysis by the Alpins method. J Cataract Refract Surg 2001;27:31-49.
29. Thibos LN, Horner D. Power vector analysis of the optical outcome of refractive surgery. J Cataract Refract Surg 2001;27:80-5.
30. Harris WF. Analysis of astigmatism in anterior segment surgery. J Cataract Surg 2001;27:107-28.
31. Naeser K, Hjortdal J. Multivariate analysis of refractive data. Mathematics and statistics of spherocylinder. J Cataract Refract Surg 2001;27:129-42.
32. Kaye SB, Patterson A. Analyzing refractive changes after anterior segment surgery. J Cataract Refract Surg 2001;27:50-60.


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