CASE REPORT

Analysis of IOL power calculations and postoperative visual outcomes in patients who have undergone radial keratotomy and laser-assisted in situ keratomileusis

Shreesha Kumar Kodavoor, MBBS, MS, DNB, Sanket R. Kulkarni, MBBS, DNB, Ramamurthy Dandapani, MBBS, MD, MNAMS, Chitra Ramamurthy, MBBS, DO

The purpose of this study was to report challenges in intraocular lens (IOL) power calculation and postoperative visual outcomes in patients undergoing phacoemulsification who have already undergone radial keratotomy (RK) and laser-assisted in situ keratomileusis (LASIK). The study is a retrospective analysis of the electronic medical records of patients. A total of 4 eyes of 3 patients were included. Patients who had previously undergone LASIK and RK and who had visually significant cataract were included. Biometry was performed using the IOLMaster, and the Barrett True-K formula was used for determining the power of the IOL. Various other formulas to calculate IOL power were obtained using the ASCRS online calculator. In this study it was found that the Barrett True-K (no history) formula yielded the most accurate biometry in this subset of patients.

J Cataract Refract Surg 2020; 8:e00023 Copyright © 2020 Published by Wolters Kluwer on behalf of ASCRS and ESCRS

Corneal refractive surgery is a commonly performed surgical procedure that can alter corneal effective power. Excimer and femtosecond laser technologies have replaced the older incisional surgeries such as radial keratotomy.1,2 As the number of patients undergoing cataract surgery after previous corneal refractive procedures has increased, the number of refractive surprises after cataract surgery has also increased. The most common refractive surprise is hyperopia, which occurs because of underestimation of intraocular lens (IOL) power in patients who have undergone myopic corrections.3-5 Hyperopia after cataract surgery can severely affect refractive outcome as pseudophakic eyes lose their accommodative ability. In addition, the amount of refractive surprise after cataract surgery depends on the amount of refractive error corrected during the refractive procedure.6-8

Radial keratotomy (RK) works by steepening the peripheral cornea and flattening the central cornea, resulting in a hyperopic shift.9 After excimer keratotomy, the anterior corneal surface changes, but the posterior corneal surface remains unaltered. Changing the ratio of power of the cornea’s anterior surface to that of the posterior surface alters the cornea’s effective refractive index. In post-RK patients, this ratio of the anterior and posterior cornea is maintained.

IOL power calculation for patients undergoing cataract surgery is mainly based on the measurement of corneal power and axial length and on predicting the effective lens position after surgery.10-12 Determination of corneal power is one of the most important steps in IOL power calculation. A constant called the keratometric index of refraction is used in the determination of corneal power.13 This constant can be used accurately if there is a fixed ratio of the anterior and posterior corneal surface curvature. However, in the post-laser-assisted in situ keratomileusis (LASIK), this ratio is altered, and the keratometric index becomes flawed and less accurate.14 In post-RK patients, the ratio of the anterior and posterior cornea is maintained; however, because the optic zone is usually small, keratometry may involve the steep peripheral area and result in overestimation of corneal power. In addition, post-RK patients often have irregular astigmatism due to asymmetric incisions.

IOL power calculation for post-LASIK and post-RK patients can be made using various formulas, such as Masket, Modified Masket, Barrett True-K, Shammas, Haigis-L, and Barrett True-K (no history).16,17 All these

Submitted: December 24, 2019 | Final revision submitted: January 23, 2020 | Accepted: January 31, 2020
From the Department of Cataract, Cornea and Refractive (Kodavoor), Department of Cataract and Refractive (Kulkarni, Dandapani), and Department of Glaucoma (Ramamurthy), The Eye Foundation, R.S.Puram, Coimbatore, India.
Corresponding author: Shreesha Kumar Kodavoor, MBBS, MS, DNB, Department of Cataract, Cornea and Refractive, The Eye Foundation, 582-A, D.B.Rd, R.S.Puram, Coimbatore, India. Email: eskay_03@rediffmail.com.

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Published by Wolters Kluwer Health, Inc.
1873-4502/$ - see frontmatter
https://doi.org/10.1097/j.jcro.0000000000000023

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formulas are included in the ASCRS calculator, which can be accessed online. A mean value using all the above formulas can also be obtained from the ASCRS online calculator.

To our knowledge, the study by Liu et al. is the only case report of unilateral eye that focuses on IOL power calculation for patients undergoing both RK and LASIK. We present a case series of 3 patients (4 eyes) who underwent cataract surgery with IOL implantation after RK and subsequent LASIK surgery (hyperopic LASIK in 1 eye and myopic LASIK in 3 eyes).

METHODS
This case series is a retrospective analysis of the data obtained from the electronic medical records of the patients. The study was approved by Institutional Review Board and the Institutional Ethics Committee.

CASE REPORTS
Patient 1
A 52-year-old man presented with complaints of blurring of vision in both eyes. He had a history of RK in both eyes 7 years ago. His corrected distance visual acuity (CDVA) was 6/9 in both eyes, with a refractive correction of +2.5 2.5 × 90 in the right eye and +3.5 3.5 × 90 in the left eye. His anterior and posterior segment examinations were within normal limits. He was advised LASIK in both eyes for correction of regression after RK. His first postoperative day uncorrected distance visual acuity (UDVA) was 6/9 in both eyes. His UDVA was stable until 6 months after LASIK, following which the patient was lost to follow-up. The patient presented to us after 11 years with blurring of vision in the right eye. His UDVA was 6/36 in the right eye, which improved to 6/12 with a refraction of +1.0 +0.75 × 10. He was diagnosed with cataract in the right eye on anterior segment examination, and his posterior segment examination was normal. Keratometry readings were obtained using the IOLMaster. Preoperative corneal astigmatism was +2.0 × 180. The Barrett True-K (no history) formula was used for IOL power calculation. He underwent phacoemulsification with IOL implantation (toric IOL) in the right eye. His 2-month postoperative UDVA was 6/7.5 in the right eye with plano refraction and no residual refractive error.

Patient 2
A 25-year-old woman presented with a history of diminution of vision and a history of RK in both eyes 4 years ago. Her CDVA was 6/9 in both eyes, with a correction of 7.5 2.75 × 189 in the right eye and 9.5 3.0 × 180 in the left eye. Her anterior segment and posterior segment examinations were within normal limits except for RK scars on both corneas. She was advised to have LASIK in both eyes for treating myopic regression after RK. Her postoperative day 1 UDVA was 6/9 in both eyes and was maintained until 6 months postoperatively. The patient presented after 15 years with diminution of vision in both eyes. Her UDVA was 6/60 in the right eye, improving to 6/24 with a refraction of 1.0 1.25 × 85, and 6/60 in the left eye, improving to 6/12 with a refraction of +0.75 2.5 × 50. She was diagnosed with cataract in both eyes. Her posterior segment examination showed myopic fundus changes. She underwent cataract surgery (phacoemulsification) with IOL implantation in the left eye followed by the right eye. An aspheric single-piece IOL was implanted in both eyes. Keratometry readings of both eyes were obtained using the IOLMaster. Preoperative corneal astigmatism was +2.55 × 155 in the right eye and +1.2 × 157 in the left eye. The Barrett True-K (no history) formula was used for IOL power calculation. Her 2-month postoperative UDVA was 6/24 in the right eye, improving to 6/9 with a refraction of +0.5/2.5 × 90, and 6/24 in the left eye, improving to 6/9 with a refraction of +0.25/1.5 × 50.

Patient 3
A 33-year-old woman presented to our hospital with complaints of diminution of vision and a history of RK in both eyes 20 years ago. Her CDVA was 6/6 in both eyes, with
a correction of 7.0 2.5 × 165 in the right eye and 8.0 2.0 × 5 in the left eye. Her anterior segment examination was within normal limits except for the RK scars on both corneas. Posterior segment examination was normal. She underwent LASIK to treat the myopic regression in both eyes. Her UDVA was 6/9 in both eyes on the postoperative day 1 and was maintained until 6 months. The patient was lost to follow-up. The patient presented to us after 13 years with diminution of vision in the left eye. Her UDVA was counting fingers at 3 m with no improvement on pinhole examination. On examination, she was diagnosed with dense cataract in the left eye (Figures 1 and 2). Posterior segment examination showed tessellated background and 360-degree barrage laser scars. She was advised phacoemulsification with IOL implantation. Keratometry values were obtained using the IOLMaster, and the IOL power was calculated using the Barrett True-K (no history) formula. Preoperative corneal astigmatism was +0.77 × 84. An aspheric single-piece IOL was implanted. Her UDVA on the postoperative day 1 was 6/9, and it was maintained at 2 months postoperatively with plano refraction and no residual refractive error.

**DISCUSSION**

Accurate biometry is one of the most important steps in cataract surgery. The IOLMaster 700 was used for biometry in all the eyes. IOL power values using multiple formulas were obtained using the ASCRS online calculator (Table 1). Of which the Barrett True-K (no history) formula was used to determine the IOL power for all eyes. The target refraction while calculating the IOL power was set as zero. In 1 eye (patient 1), a toric IOL was implanted to address high corneal astigmatism. However, in the remaining eyes, a toric IOL could not be implanted because of patient monetary constraints. In our study, we found that the Barrett True-K (no history) formula yielded the most accurate biometry in all eyes. As seen from the difference values between the power of the implanted IOL and the IOL power predicted using different formulas, we can infer that there would have been a significant postoperative residual refractive error if other formulas were used for determining the IOL power (Tables 2–4). Our results are partly in concurrence with the results published by Liu et al., who concluded that the Barrett True-K (no history), Shammas, and Haigis-L were the most accurate formulas for IOL power calculation in post-RK and post-LASIK patients. However, in our case series, Haigis-L showed considerable differences from the IOL power implanted and would have resulted in significant postoperative refractive error. In our case series, other than the Barrett True-K (no history) formula, accurate biometry (within +/−0.5 D of the IOL power implanted) was obtained in at least 2 eyes using the Shammas formula and the mean value obtained from the ASCRS calculator.

**CONCLUSION**

This case series provides important insights regarding IOL power calculation in patients who have undergone RK followed by LASIK and subsequent cataract surgery. We conclude that the Barrett True-K (no history) formula yields the most accurate biometry in this subset of patients. The ASCRS online calculator is a very useful tool for IOL power calculations in post-LASIK and post-RK patients. Our results suggest that for IOL power calculation, using only the post-LASIK data can be sufficient, and the post-RK status can be ignored. Our study has a few limitations such as

| Table 1. Comparison between the IOL power obtained using different formulas and preoperative and postoperative astigmatism. |
|---|---|---|---|
| **Formula** | **Patient 1** | **Patient 2** | **Patient 3** |
| | **Right Eye** | **Right Eye** | **Left Eye** | **Left Eye** |
| Shammas | 21.94 D | 22.75 D | 19.78 D | 20.92 D |
| Haigis-L | 22.74 D | 23.83 D | 20.80 D | 21.53 D |
| Masket | 20.97 D | 21.24 D | 18.56 D | 19.56 D |
| Modified Masket | 20.73 D | 22.06 D | 19.58 D | 20.40 D |
| Barrett True-K | 22.66 D | 21.7 D | 20.07 D | 21.54 D |
| Barrett True-K (no history) | 23.23 D | 21.02 D | 19.78 D | 21.04 D |
| ASCRS mean IOL power | 21.97 D | 22.20 D | 19.73 D | 20.92 D |
| IOL power implanted | 23.0 D (+2.25 cyl) | 21.0 | 20.0 | 21.0 D |
| Preoperative corneal astigmatism | +2.0@180 | +2.55@155 | +1.2@157 | +0.77@84 |
| Residual refractive error | NIL | +0.5/−2.5@90 | +0.25/−1.5@50 | NIL |

IOL = intraocular lens

| Table 2. Difference between the IOL power obtained using different formulas and the IOL power implanted for patient 1. |
|---|---|---|
| **Formula** | **Right Eye** | **Difference** |
| Shammas | 21.94 D | +1.06 |
| Haigis-L | 22.74 D | +0.26 |
| Masket | 20.97 D | +2.03 |
| Modified Masket | 20.73 D | +2.27 |
| Barrett True-K | 22.66 D | +0.34 |
| Barrett True-K (no history) | 23.23 D | −0.23 |
| ASCRS mean IOL power | 21.97 D | +1.03 |

IOL = intraocular lens
conclusively establish a standard formula for IOL power as a small sample size and retrospective nature. More prospective studies with large sample sizes are required to conclusively establish a standard formula for IOL power calculation in these patients.

**WHAT WAS KNOWN**
- Haigis-L is the most accurate formula for intraocular lens (IOL) power calculation in patients who have undergone radial keratotomy (RK) and subsequent laser-assisted in situ keratomileusis (LASIK), followed by the Barrett True-K (no history) and Shammas formulas.
- However, the accuracy of these formulas is observed in only 1 eye, and no other reports are available regarding the same.
- These formulas are accurate in post-myopic LASIK patients, and no data are available regarding their accuracy in post-hyperopic LASIK patients.

**WHAT THIS PAPER ADDS**
- The Barrett True-K (no history) formula might be superior in accurately calculating the IOL power in post-RK and post-LASIK patients.
- The Haigis-L and Shammas formulas might not be accurate in calculating the IOL power in all eyes having a post-RK, LASIK status.
- The Barrett True-K (no history) formula might accurately calculate the IOL power in eyes that have undergone RK followed by subsequent myopic or hyperopic LASIK.

### Table 3. Difference between the IOL power obtained using different formulas and the IOL power implanted for patient 2.

| Formula                     | Right Eye | Difference | Left Eye | Difference |
|-----------------------------|-----------|------------|----------|------------|
| Shammas                     | 22.75 D   | +1.75      | 19.78 D  | –0.22      |
| Haigis-L                    | 23.83 D   | +2.83      | 20.80 D  | +0.80      |
| Masket                      | 21.24 D   | +0.24      | 18.56 D  | –1.44      |
| Modified Masket             | 22.06 D   | +1.06      | 19.58 D  | –0.42      |
| Barrett True-K              | 21.7 D    | +0.7       | 20.07 D  | +0.07      |
| Barrett True-K (no history) | 21.02 D   | +0.02      | 19.78 D  | –0.22      |
| ASCRS mean IOL power        | 22.20 D   | +1.20      | 19.73 D  | –0.27      |

IOL = intraocular lens

### Table 4. Difference between the IOL power obtained using different formulas and the IOL power implanted for patient 3.

| Formula                | Left Eye | Difference |
|------------------------|----------|------------|
| Shammas                | 20.92 D  | –0.08      |
| Haigis-L               | 21.53 D  | +1.53      |
| Masket                 | 19.56 D  | –1.44      |
| Modified Masket        | 20.40 D  | –0.60      |
| Barrett True-K         | 21.54 D  | +0.54      |
| Barrett True-K (no history) | 21.04 D | +0.04      |
| ASCRS mean IOL power   | 20.92 D  | –0.08      |

IOL = intraocular lens

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**Disclosures:** None of the authors has a financial or proprietary interest in any material or method mentioned.

**First author:**
Shreeshita Kumar Kodavoor, MBBS, MS, DNB
Department of Cataract, Cornea and Refractive, The Eye Foundation, R.S.Puram, Coimbatore, India