ORIGINAL ARTICLE

# Calculation of Intraocular Lens Power Using Orbscan II Quantitative Area Topography After Corneal Refractive Surgery

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## ABSTRACT

**PURPOSE:** To present the prospective application of the Orbscan II central 2-mm total-mean corneal power obtained by quantitative area topography in intraocular lens (IOL) calculation after refractive surgery.

**METHODS:** Calculated and achieved refraction and the difference between them were studied in 77 eyes of 61 patients with previous radial keratotomy (RK), RK and additional surgeries, myopic LASIK, myopic photorefractive keratectomy (PRK), or hyperopic LASIK who underwent phacoemulsification without complications in 3 eye centers. All IOL calculations used the average from the central 2-mm Orbscan II total-mean power of maps centered on the pupil without the use of previous refractive data. Six IOL styles implanted within the bag were used.

**RESULTS:** Using the SRK-T formula, the overall calculated refraction was −0.64±0.93 diopters (D). The overall achieved spherical equivalent refraction (−0.52±0.79 D) was ±1.00 D in 78% of eyes and ±2.00 D in 99% of eyes. The overall difference between the calculated and achieved refraction (0.12±0.93 D, *P*=.27) was ±1.00 D in 77% of eyes and ±2.00 D in 96% of eyes. This difference was ±1.00 D in 77% of eyes with RK (*P*=.70) and in 90% of eyes with myopic LASIK (*P*=.34) or myopic PRK (*P*=.96). In eyes with RK followed by LASIK, a trend toward undercorrection was noted (*P*=.03). In eyes with hyperopic LASIK, a trend toward overcorrection was noted (*P*=.005).

**CONCLUSIONS:** In eyes with previous corneal refractive surgery, IOL power calculation can be performed with reasonable accuracy using the Orbscan II central 2-mm total-mean power. This method had better outcomes in eyes with previous RK, myopic LASIK, and myopic PRK than in eyes with hyperopic LASIK or RK with LASIK. [*J Refract Surg*. 2009;xx:xxx-xxx.]


Although not currently popular, it has been estimated that approximately 1.5 million eyes underwent radial keratotomy (RK) in Brazil since 1980. Almost 200,000 refractive procedures were performed in Brazil in 2003.[1] There are more than 800,000 LASIK procedures performed annually by members of the American Society of Cataract and Refractive Surgery[2]—currently the most popular technique to correct myopia.[2-4] With these large numbers of refractive surgeries around the world, cataract surgery with intraocular lens (IOL) implantation following refractive surgery will become increasingly common. Intraocular lens power calculation in these cases is challenging. Significant postoperative hyperopic error (undercorrection) in eyes with previous myopic surgery and myopic error (overcorrection) in eyes with previous hyperopic surgery has been reported. The inexact IOL calculation seems to be due to biometric inaccuracies, incorrect corneal power assessment, or less accurate IOL formulas.[5-17]

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In 2004, Sónego-Krone et al[18] reported that the refractive change at the corneal plane after myopic LASIK (calculated by subtracting the postoperative residual refractive defect from the preoperative ametropia) had a difference of 0.07±0.62 D with the corneal power change determined by quantitative area topography in a 2-mm-diameter central zone of Orbscan II (Bausch & Lomb, Rochester, NY) total-mean postoperative maps. With a comparable change (difference of −0.08±0.53 D), the average of a 4-mm-diameter central zone from an Orbscan II total-optical postoperative map was almost always <1.00 D steeper.[18-21] Quantitative area topography is distinct from quantitative point topography, which assesses the average of only two single steeper and flatter values.[22] The total-mean power maps represent the spherical equivalent refraction of both corneal curvatures with regard to the corneal thickness and are comparable to the equivalent power of the cornea assessed by the thick lens formula.[23] The total-optical power maps represent the ray tracing of light through the whole cornea.[23]

In the clinical history method,[8-13,15] the change in refraction is subtracted from the anterior corneal curvature before the refractive surgery to obtain the keratometric value to be used in IOL formulas. In the Sónego-Krone et al approach,[18] the pre- and postoperative average total-mean and total-optical powers were determined from all points of both surfaces within specific zones. The great advantage of this method is that the final total corneal powers to be used in IOL calculation may be obtained directly from the topographic maps, as measured after the previous corneal refractive surgery[18,19] without depending on regression formulas,[24,25] artificial refraction indices,[16,26,27] contact lens over-refraction,[28-30] aphakic intraoperative refraction,[31,32] previous refractive[11-14,33-39] or topographic data, algorithms, or correction factors.[39,40] This method has already been evaluated in a retrospective comparison between the ideal IOL power calculated for emmetropia and the IOL power calculated using the SRK-T formula in 10 eyes of 7 patients who underwent RK. By using the flatter of either 2-mm total-mean or 4-mm total-optical Orbscan II powers, 8 of 10 cases would have had a residual ametropia of ±1.00 diopter (D).[19]

The purpose of this article is to present a prospective application of the Orbscan II quantitative area topography in IOL calculation in 77 eyes from 61 patients with previous myopic or hyperopic refractive surgeries who underwent phacoemulsification with intraocular lens implantation in three independent institutions.

## PATIENTS AND METHODS

As a result of their participation in the Keranet list, three surgeons (R.W.W., S.M.H., and C.G.A.) decided to share their experience regarding the calculation of IOL power in patients who had undergone previous refractive surgery. Thus, despite no original common protocol, this multicenter study reports the outcomes of their prospectively collected cases with previous refractive surgery between 2004 and 2006. Uneventful clear cornea phacoemulsification and IOL implantation were performed in 13 eyes of 11 patients at the Institute of Cataract, Department of Ophthalmology, Paulista School of Medicine, Federal University of São Paulo, Brazil with a recorded postoperative follow-up between 1.5 to 24 months at the time collection of data was stopped. The study also includes 29 eyes of 20 patients from the Upstate Medical Center, State University of New York, Syracuse, New York with a postoperative follow-up between 1 and 24 months, and 35 eyes of 30 patients from the Piedmont Better Vision LLC, Atlanta, Georgia, with a postoperative follow-up between 1 and 14 months.

Cases were grouped according to the institution of origin and type of refractive surgery. There were 30 eyes with previous RK (4, 8, or 16 incisions) or RK with arcuate keratotomy (AK); 7 eyes with RK followed by LASIK (2 eyes with two LASIK procedures); 1 eye with RK and automated lamellar keratoplasty (ALK); 1 eye with RK, vitrectomy, and retinopexy; 10 eyes with myopic photorefractive keratectomy (PRK); 22 eyes with myopic LASIK; and 6 eyes with hyperopic LASIK. Most cases did not have previous refractive data available.

This study reports the analysis of the achieved refraction and its difference (deviation) from what it was calculated using the average of the 2-mm–diameter central zone from the Orbscan II total-mean power maps centered on the pupil, as measured after the previous corneal refractive surgery (Fig 1). The Orbscan II statistical analysis device showed a window with the average value used in IOL calculation of each case (see Fig 1). Corneal power was also assessed using one or more of the following methods: the NIDEK OPD-Scan wavefront aberrometer (NIDEK Co Ltd, Gamagori, Japan), the IOLMaster (Carl Zeiss, Jena, Germany), the effective refractive power (EffRP, from the Holladay Diagnostic Summary),[41] the Sim-K obtained from the Orbscan II or the EyeSys Videokeratographer (EyeSys, Houston, Tex), and the Orbscan II 4-mm–diameter total-optical power. The aim was to observe whether a flatter corneal power would be obtained by any of these methods and to assist the surgeon in the final decision of the corneal power for the calculation of IOL power. No statistical comparative analysis was performed. Each institution used its usual biometric method and biometer.

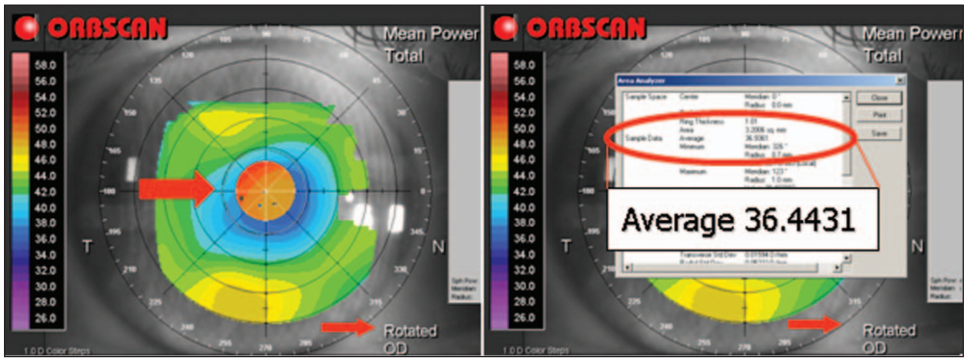


**Figure 1.** Total-mean map rotated (small arrows) to the pupil showing the area analyzed (arrow at left) with 1-mm radius. The average value (at right inside oval) shown at the window data was applied to IOL calculation in eyes with previous refractive surgery.

All surgeries were uncomplicated with placement of the IOLs inside the capsular bag by a single surgeon from each institution (E.S.S., R.W.W., S.M.H.). Each surgeon was free to choose the surgical phacoemulsification technique and unit, IOL formula, and posterior chamber IOL model. The group from São Paulo used only MA30AC AcrySof IOLs (Alcon Laboratories Inc, Ft Worth, Tex) with the SRK-T formula. The group from New York used only LI61U IOLs (Bausch & Lomb, Rochester, NY) with either the SRK-T or Holladay I formula. The group from Atlanta used MA60AC, SA30AT, SA60AT or SN60WF AcrySof IOLs (Alcon Laboratories Inc) with mainly the SRK-T; however, Holladay, Hoffer-Q, and Haigis formulas were also used.

This study was designed as an observational case series. Patients were not age- or gender-matched. No separate control was used. All refraction data were converted and expressed with negative cylinder. As recommended elsewhere,[18] compound names of Orbscan II maps use a hyphen. The difference from the calculated refraction in diopters was defined as the spherical equivalent of final refraction minus the expected refractive outcome for each formula used. Pearson correlation was calculated between the achieved postoperative spherical equivalent and the calculated refraction for all cases together and for each group classified by the type of previous refractive surgery. The two-tailed paired *t* test was used for comparison of both variables in all cases and in each group. The two-tailed Wilcoxon signed ranks test was also used for groups with less than 20 cases (myopic PRK, hyperopic LASIK, RK and LASIK, and RK and other surgeries). Analysis of variance (ANOVA) and Tukey tests were used for comparison among groups. An alpha risk of 0.05 was established. Unless otherwise indicated, data are expressed as mean±standard deviation.

## RESULTS

Individual results from each institution are summarized in Tables 1, 2, and 3. Final postoperative best spectacle-corrected visual acuity (BSCVA) of all eyes from the three groups was 20/30 or better. The average of the Orbscan II central 2-mm–diameter total-mean power was always applied in the IOL calculation although a flatter corneal power was found in two cases using the clinical history method, in two cases using the Orbscan II Sim-K, and in one case using the average of the Orbscan II central 4-mm–diameter total-optical power. All other corneal powers assessed by other methods and equipments were steeper.

The overall calculated refraction (−0.64±0.93 D) with the SRK-T formula was not different (*P*=.27) than the overall achieved spherical equivalent (−0.52±0.79 D) (Table 4, Fig 2). Both variables were not different in cases with previous RK or RK with AK (*P*=.70), myopic PRK (*P*=.96), and myopic LASIK (*P*=.34). Both variables were significantly different in cases with RK followed by LASIK (*P*=.03) and with hyperopic LASIK (*P*=.005).

The achieved spherical equivalent refraction was within±0.25 D in 18 (23%) of 77 eyes, ±0.50 D in 41 (53%) ,±1.00 D in 60 (78%), ±1.50 D in 70 (90%), and ±2.00 D in 76 (99%). Analysis of variance test showed that the achieved spherical equivalent refraction obtained with the SRK-T formula was not different among groups (*P*=.82). Tukey multiple comparisons confirmed no difference among groups ($P \geqslant .89$).

The overall difference between the calculated refraction with the SRK-T formula and the achieved spherical equivalent refraction had a negative correlation with such expected refraction (Pearson=−0.61) but a positive correlation with the achieved spherical equivalent refraction (Pearson=0.40). The correlation between the overall expected refraction and the final result was 0.43. This correlation was 0.37 in cases with RK or RK with AK, 0.43 in RK with LASIK, and 0.58 in myopic and 0.87 in hyperopic LASIK. Despite good final results, there was no correlation in cases with myopic PRK (Pearson=0.06).

The difference between the calculated refraction with SRK-T formula and the achieved spherical equivalent refraction (Table 4) in all 77 eyes was 0.12±0.93 D with a 95% confidence interval from −0.09 to 0.33 (Fig 2). This difference was within ±0.25 D in 17 (22%) of

TABLE 1

**Eyes With Previous Refractive Surgery That Underwent Phacoemulsification With IOL Implantation at the Federal University of São Paulo**

| Previous Refractive Surgery | Orbscan II 2-mm Total-mean Power | IOL for Emmetropia | IOL Implanted (D) | Calculated Refraction With SRK-T | Achieved Refraction | Final Spherical Equivalent | Difference With SRK-T |
|---|---|---|---|---|---|---|---|
| RK | 31.53 | 20.16 | 21.50 | −1.10 | +0.50 −2.00 × 90º | −0.50 | +0.60 |
| RK | 37.84 | 19.64 | 21.00 | −1.02 | −2.00 × 90º | −1.00 | +0.02 |
| RK | 35.67 | 23.31 | 25.00 | 1.33 | −0.50 –2.50 × 80º | −1.75 | −0.42 |
| RK | 35.38 | 19.11 | 20.50 | −1.08 | −1.75 × 135º | −0.875 | +0.205 |
| RK | 33.52 | 18.83 | 19.00 | −0.14 | −2.25 × 100º | −1.125 | −0.985 |
| RK | 40.60 | 13.24 | 14.00 | −0.53 | −0.50 –0.75 × 90º | −0.875 | −0.345 |
| RK | 38.78 | 9.98 | 10.00 | −0.02 | −0.75 | −0.75 | −0.73 |
| M-PRK | 33.36 | 20.20 | 20.50 | −0.30 | −0.25 –0.75 × 90° | −0.625 | −0.325 |
| M-LASIK | 33.36 | 21.67 | 22.00 | −0.26 | −0.75 | −0.75 | −0.49 |
| M-LASIK | 36.44 | 1.15 | 22.00 | −0.58 | −1.00 –1.00 × 175º | −1.50 | −0.92 |
| M-LASIK | 43.60 | 20.27 | 20.50 | −0.23 | −0.50 | −0.50 | −0.27 |
| M-LASIK | 33.36 | 18.55 | 19.00 | −0.45 | +1.25 –1.75 ×180° | +0.375 | +0.825 |
| M-LASIK | 30.71 | 20.61 | 21.00 | −0.39 | +1.0 –1.50 × 170° | +0.25 | +0.64 |
| Mean | 35.56 | 18.98 | 19.69 | −0.57 | | −0.74 | −0.17 |
| SD | 3.60 | 3.56 | 3.82 | 0.42 | | 0.59 | 0.59 |
| Maximum | 43.60 | 23.31 | 25.00 | −0.02 | | +0.38 | +0.83 |
| Minimum | 30.71 | 9.98 | 10.00 | −1.33 | | −1.75 | −0.99 |

*IOL = intraocular lens, difference = final spherical equivalent minus calculated refraction, RK = radial keratotomy, M−LASIK = myopic LASIK, SD = standard deviation*

77 eyes, ±0.50 D in 30 (39%), ±1.00 D in 59 (77%), and ±2.00 D in 74 (96%) eyes. The largest difference was found in cases with hyperopic LASIK and RK followed by LASIK or with other surgeries. Figures 3 and 4 suggest a trend to positive deviation in RK with subsequent surgeries and to negative deviation after hyperopic LASIK. Analysis of variance test showed that the difference between the calculated refraction with the SRK-T formula and the achieved spherical equivalent refraction was not the same among groups (*P*=.001). Tukey multiple comparisons confirmed this finding among cases with hyperopic LASIK and with RK (*P*=.01), myopic LASIK (*P*=.009), myopic PRK (*P*=.03), or RK followed by LASIK (*P*=.0002). There was no difference among cases with RK and myopic LASIK (*P*=.995), myopic PRK (*P*=.999), or RK with LASIK (*P*=.07); among cases with myopic LASIK and with myopic PRK (*P*=1.00), or RK with LASIK (*P*=.15); and among cases with myopic PRK and with RK and LASIK (*P*=.22).

The difference between the calculated refraction with the Holladay formula and the achieved spherical equivalent refraction in 64 eyes was 0.04±0.96 D (range: −1.97 to 2.55 D) and within ±0.25 D in 13 (20%) of 64 eyes, ±0.50 D in 26 (41%), ±1.00 D in 47 (73%), and ±2.00 D in 62 (97%) eyes. The difference between the calculated refraction with the Hoffer Q formula and the achieved spherical equivalent refraction in 35 eyes was −0.44±0.79 D (range: −1.55 to 1.68 D) and within ±0.25 D in 10 (29%) of 35 eyes, ±0.50 D in 13 (37%), ±1.00 D in 25 (71%), and ±2.00 D in 35 (100%) eyes. The difference between the calculated refraction with the Haigis formula and the achieved spherical equivalent refraction in 35 eyes was −0.90±0.82 D (range: −2.16 to 1.05 D) and within±0.25 D in 3 of 35 (9%) eyes, ±0.50 D in 11 (31%), ±1.00 D in 18 (51%), and ±2.00 D in 32 (91%) eyes.

## DISCUSSION

This is the first and largest prospective application of the method developed by Sónego-Krone et al[18] using the Orbscan II in the calculation of IOL power in eyes with previous myopic or hyperopic refractive surgery. Topography[41,42] and Orbscan II[18,19,43-50] have been recommended for better corneal power assessment in IOL calculation. Orbscan II supplies several corneal power or curvature maps named according to the mathematic method used to achieve the value in diopters.[18,19,22,43,51]

According to the refractive index applied and the analyzed portion of the cornea, maps may be keratometric, anterior, posterior, total, or thickness power maps. Keratometric maps represent an assumed whole corneal curvature derived from the anterior surface by using a fictitious refraction index of 1.3375. Methods that use maps derived only from the anterior surface data may be inadequate for IOL calculation because they do not evaluate the entire corneal optical system or may assume values for the posterior surface curvature.[37] In fact, keratometric values such as Sim-K tend to underestimate the change after myopic LASIK, even when the central point is assessed.[18] On the other hand, anterior, posterior, and total maps are calculated using physiologic refraction indices of air (1.0), cornea (1.376), and aqueous humor (1.336). Axial (saggital) and tangential (meridional or instantaneous) Orbscan II maps may be derived either from the Placido or elevation data. Orbscan II seems to have the ability to combine both Placido and elevation data to better display these last two maps.[51] Although this apparent integration was effective through the tools menu and surface rotation device, no information from the manufacturer was available to explain how it happens. Mean power maps represent the spherical equivalent of each point in all meridians from each corneal surface. Total-mean maps are the addition of the anterior-mean, posterior-mean, and thickness-mean maps. Optical power maps, also called refractive or Snell maps, represent the focal properties of the cornea. Total-optical maps consider the ray tracing of light through the whole cornea.[18,20,23,43,51]

The corneal power applied in this study is the average of all points contained within the 2-mm–diameter central zone of Orbscan II total-mean maps centered on the pupil, as measured directly from corneas with previous refractive surgery. This value was not chosen arbitrarily among the corneal powers assessed. The methods used had the purpose to verify which one provides the

TABLE 2

**Eyes With Previous Refractive Surgery That Underwent Phacoemulsification With IOL Implantation at the State University of New York**

| Previous Refractive Surgery | Orbscan II 2-mm Total-mean Power | IOL Implanted | Calculated Refraction With SRK-T | Calculated Refraction With Holladay I | Achieved Refraction | Final Spherical Equivalent Refraction | Difference With SRK-T | Difference With Holladay I |
|---|---|---|---|---|---|---|---|---|
| M-PRK | 38.92 | 21.00 | −1.08 | −0.68 | −1.25 −0.50 × 85° | −1.50 | −0.42 | −0.82 |
| M-PRK | 37.24 | 21.50 | −0.48 | −0.03 | −0.75 −0.50 × 110° | −1.00 | −0.52 | −0.97 |
| M-PRK | 36.85 | 17.50 | −0.07 | 0.00 | +0.25 −0.25 × 10° | +0.125 | +0.195 | +0.125 |
| M-PRK | 40.04 | 19.50 | −0.73 | −0.39 | +0.50 −0.50 × 155° | +0.25 | +0.98 | +0.64 |
| M-PRK | 40.04 | 19.00 | −0.71 | −0.43 | +0.25 −.50 × 165° | 0.00 | +0.71 | +0.43 |
| M-PRK | 41.62 | 19.00 | −1.17 | −0.89 | −0.25 × 175° | −0.125 | +1.045 | +0.765 |
| M-PRK | 34.43 | 21.50 | −0.45 | −0.14 | −0.25 −0.50 × 150° | −0.50 | −0.05 | −0.36 |
| M-PRK | 33,81 | 21.50 | −0.02 | +0.30 | −0.25 −0.50 × 145° | −0.50 | +0.89 | +0.57 |
| M-LASIK | 33.97 | 23.00 | −0.91 | −0.51 | −0.75 −0.50 × 0° | −1.00 | −0.09 | −0.49 |
| M-LASIK | 34.08 | 21.00 | −0.47 | −0.22 | +0.25 −1.00 × 170° | −0.25 | +0.22 | −0.03 |
| M-LASIK | 34.36 | 22.00 | −1.61 | −1.35 | −1.50 −1.00 × 95° | −2.00 | +0.11 | −0.15 |
| M-LASIK | 33.53 | 23.50 | −0.12 | +0.39 | −1.25 × 107° | −0.625 | −0.50 | −1.01 |
| H-LASIK | 39.47 | 23.50 | +1.25 | +1.30 | +0.5 −0.25 × 105° | +0.325 | −0.88 | −0.93 |
| H-LASIK | 40.28 | 23.50 | +0.92 | +0.92 | +0.25 −0.25 × 170° | +0.125 | −0.80 | −0.80 |

*IOL = intraocular lens, difference = final spherical equivalent minus calculated refraction, RK = radial keratotomy, M-PRK = myopic photorefractive keratectomy, M-LASIK = myopic LASIK, SD = standard deviation*

TABLE 2 CONTINUED

**Eyes With Previous Refractive Surgery That Underwent Phacoemulsification With IOL Implantation at the State University of New York**

| Previous Refractive Surgery | Orbscan II 2-mm total-mean power | IOL Implanted | Calculated Refraction With SRK-T | Calculated Refraction With Holladay I | Achieved Refraction | Final Spherical Equivalent Refraction | Difference With SRK-T | Difference With Holladay I |
|---|---|---|---|---|---|---|---|---|
| RK | 40.21 | 22.00 | −0.17 | +0.15 | +0.50 −0.50 × 135º | +0.25 | +0.42 | +0.10 |
| RK | 32.81 | 19.50 | −0.47 | −0.38 | +0.50 −0.50 × 135º | +0.25 | +0.72 | +0.63 |
| RK | 36.83 | 16.00 | −0.97 | −1.08 | −0.75 × 145º | −0.375 | +0.595 | +0.705 |
| RK | 36.56 | 16.50 | −0.50 | −0.65 | −0.50 −1.75 × 150º | −1.375 | −0.875 | −0.725 |
| RK | 34.80 | 21.00 | −0.11 | −0.40 | −0.50 × 15º | −0.25 | −0.14 | +0.15 |
| RK | 34.99 | 21.50 | −0.79 | 0.48 | +0.25 −0.75 × 0º | −0.125 | +0.665 | +0.355 |
| RK | 34.70 | 18.50 | +0.12 | −0.03 | +0.75 −1.25 × 0º | +0.125 | +0.005 | +0.155 |
| RK | 33.81 | 21.50 | −0.02 | +0.30 | −0.25 −0.50 × 145° | −0.50 | +0.89 | +0.57 |
| RK | 42.88 | 20.00 | −1.87 | −1.70 | −0.75 × 167° | −0.375 | +1.5 | +1.33 |
| RK | 40.16 | 21.50 | −1.16 | +0.75 | −0.50 −0.25 × 166° | −0.625 | +0.54 | −1.37 |
| RK | 44.28 | 13.00 | +2.09 | +2.09 | +0.50 −0.75 ×130° | +0.125 | −1.97 | −1.97 |
| RK | 42.23 | 19.00 | +0.73 | +0.62 | −0.25 | −0.25 | −0.98 | −0.87 |
| RK | 34.69 | 19.00 | −0.50 | −0.70 | −0.75 −0.50 × 96° | −1.00 | −0.50 | −0.30 |
| RK | 34.98 | 19.50 | −0.79 | −0.87 | +1.00 −1.00 × 0° | +0.50 | +1.29 | +1.37 |
| RK | 32.70 | 21.00 | +0.31 | +0.37 | +0.75 −0.75 × 50° | +0.375 | +0.06 | 0.00 |
| Mean | 37.00 | 20.04 | −0.34 | −0.13 | −0.34 | +0.11 | −0.10 | |
| SD | 3.50 | 2.24 | 0.84 | 0.80 | 0.61 | 0.79 | 0.80 | |
| Maximum | 44.28 | 23.50 | +2.09 | +2.09 | +0.50 | +1.50 | +1.37 | |
| Minimum | 32.7 | 13.00 | −1.87 | −1.70 | −2.00 | −1.97 | −1.97 | |

*IOL = intraocular lens, difference = final spherical equivalent minus calculated refraction, RK = radial keratotomy, M-PRK = myopic photorefractive keratectomy, M-LASIK = myopic LASIK, SD = standard deviation*

flattest corneal power as it was recommended elsewhere.[15] It is important to realize that the average dioptric values obtained by quantitative area topography vary according to the size and shape (circle or ring) of the assessed zone, type of previous refractive surgery, amount of laser energy, and ablation depth shape.[18,43] Thus, the deeper ablation at the center produces a flatter value at the central point that tends to overestimate the dioptric change after myopic LASIK or PRK. This average becomes steeper, closer to the preoperative original value, and tends to underestimate the refractive change when more peripheral points are included in larger zones.[18] The diameter of 2 mm established the area where both trends cross each other in the total-mean maps after myopic LASIK.[18] Presently, no one has yet verified how the size of the assessed zones affects the Orbscan II total corneal powers after hyperopic surgeries. Our recommendation to center maps by means of the Orbscan II surface rotation device to the same reference used in previous refractive surgeries (ie, pupil or line of sight) becomes more important when small zones are assessed.[43,51] After RK, a 2-mm central zone concentric to the pupil would have more probabilities to be within the 3-mm central incision-free area usually used in such procedures whereas a larger diameter (ie, 4 mm) may increase the risk or error including the beginning of incisions.[43]

Different Orbscan II maps require zones of analysis with different sizes to better reflect the refractive change at the corneal plane after myopic LASIK because the corneal curvature and power are calculated by different mathematic methods.[43,51] In addition to the central 2-mm zone of the Orbscan II total-mean map, the average power from the central 4-mm zone of the total-optical map also reflected accurately the refractive change after myopic LASIK,[18,52] and it has been already suggested as a good option for IOL calculation after myopic PRK and LASIK.[53] The central 5-mm zone of the total-axial map not centered on a common reference mark[45] and the paracentral 1.5- to 2-mm ring zones of the total-optical map[48] have also produced good results.

Anterior and posterior curvature maps of the Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) are mathematically derived from elevation data obtained from Scheimpflug slit images of the anterior segment of the eye. The Pentacam's true net power is basically the addition of both corneal curvatures by means of the Gaussian optics formula. However, we did not find in the manufacturer's information whether the equivalent K readings suggested for IOL calculation result from

TABLE 3

**Eyes With Previous Refractive Surgery That Underwent Phacoemulsification With IOL Implantation at Piedmont Better Vision LLC of Atlanta**

| Previous Refractive Surgery | Orbscan II 2-mm Total-mean Power | IOL Implanted | Achieved Refraction | Final Spherical Equivalent Refraction | Difference With | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | SRK-T | Holladay I | Hoffer Q | Haigis | History-derived K and SRK-T |
| RK 4 incisions | 43.70 | 20.50 | −1.25 | −1.25 | −1.50 | −1.52 | −1.55 | −2.09 | −0.83 |
| RK 8 incisions | 37.10 | 22.00 | −0.25 −0.50 × 90° | −0.50 | +1.40 | +1.06 | +0.20 | −0.45 | — |
| RK 16 incisions | 39.00 | 21.00 | −2.00 | −2.00 | −0.18 | −0.51 | −0.90 | −1.74 | +1.10 |
| RK 8 incisions+AK | 38.25 | 22.50 | −0.50 −1.25 × 110° | −1.125 | +0.64 | +0.16 | −0.33 | −1.00 | — |
| RK 8 incisions+AK | 38.60 | 24.50 | −0.50 × 150° | −0.25 | −0.13 | −0.13 | −1.05 | 0.25 | — |
| RK 8 incisions+AK | 32.30 | 27.50 | +0.50 −1.0 × 175° | 0.00 | +1.21 | +0.42 | −1.00 | −1.76 | — |
| RK 8 incisions+AK | 30.20 | 28.50 | +0.75 −0.50 × 165° | +0.50 | +1.17 | +0.35 | −1.40 | −2.13 | — |
| RK 8 incisions+AK | 38.95 | 18.50 | −0.25 −0.50 × 90° | −0.50 | 0.00 | −0.20 | −0.60 | −1.23 | — |
| RK+ALK | 37.77 | 17.00 | +0.75 −0.50 × 45° | +0.50 | +1.65 | +1.71 | +0.90 | +0.54 | +3.46 |
| RK+Rpx+PPV | 39.44 | 17.00 | +0.50 −0.75 × 15° | +0.125 | +0.84 | +0.81 | +0.33 | −0.20 | — |
| RK+LASIK | 39.40 | 20.00 | −1.75 −0.25 × 90° | −1.875 | +0.90 | +0.79 | +0.23 | −0.29 | — |
| RK+LASIK | 38.93 | 20.50 | −0.75 −0.50 × 130° | −1.00 | −0.38 | −0.72 | −1.10 | −1.62 | — |
| RK+LASIK | 37.44 | 24.00 | +0.75 −2.50 × 80° | −0.50 | +1.21 | +0.64 | +0.10 | −0.52 | — |
| RK+LASIK | 35.17 | 21.00 | −0.75 × 165° | +0.375 | +1.57 | +1.43 | +0.13 | −0.28 | — |
| RK+LASIK | 38.11 | 19.50 | +1.0 −1.25 × 65° | +0.375 | +2.62 | +2.55 | +1.68 | +1.05 | — |
| RK+2 LASIK | 40.15 | 19.50 | −0.75 × 170° | −0.375 | +0.62 | +0.33 | +0.13 | −0.48 | — |
| RK+2 LASIK | 39.66 | 20.00 | +0.75 −0.75 × 130° | +0.375 | +0.67 | +0.30 | +0.08 | −0.57— | |

*IOL = intraocular lens, difference = final spherical equivalent minus calculated refraction, RK = radial keratotomy, AK = arcuate keratotomy, ALK = automated lamellar keratoplasty, Rpx = retinopexy, PPV = pars-plana vitrectomy, M-PRK = myopic photorefractive keratectomy, M-LASIK = myopic LASIK, H-LASIK = hyperopic LASIK, SD = standard deviation*

TABLE 3 CONTINUED

**Eyes With Previous Refractive Surgery That Underwent Phacoemulsification With IOL Implantation at Piedmont Better Vision LLC of Atlanta**

| | | | | | Difference With | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Previous Refractive Surgery | Orbscan II 2-mm Total-mean Power | IOL Implanted | Achieved Refraction | Final Spherical Equivalent Refraction | SRK-T | Holladay I | Hoffer Q | Haigis | History-derived K and SRK-T |
| M-PRK | 38.70 | 18.50 | −0.50 −1.25 × 10° | −1.125 | −0.89 | −1.10 | −1.53 | −1.70 | — |
| M-LASIK | 40.62 | 19.00 | −0.75 | −0.75 | −0.58 | −0.86 | −0.95 | −0.75 | +0.75 |
| M-LASIK | 40.45 | 20.00 | +0.25 −0.75 × 160° | −0.125 | +0.46 | +0.18 | +0.08 | −1.27 | +1.705 |
| M-LASIK | 38.90 | 21.50 | −1.25 × 158° | −0.625 | +0.08 | −0.36 | −0.63 | −0.63 | +0.765 |
| M-LASIK | 38.30 | 22.00 | −1.0 −1.50 × 25° | −1.75 | −0.01 | −0.43 | −0.95 | −1.56 | +0.38 |
| M-LASIK | 39.63 | 18.50 | +0.25 −1.25 × 63° | −0.375 | −0.05 | −0.29 | −0.58 | −1.20 | — |
| M-LASIK | 39.58 | 19.00 | −1.25 −1.0 × 160° | −1.75 | −0.94 | −1.18 | −1.55 | −1.85 | −0.42 |
| M-LASIK | 39.60 | 20.50 | −3.0 −0.25 × 135° | −3.125 | −0.47 | −0.66 | −1.13 | −1.69 | — |
| M-LASIK | 36.30 | 19.50 | −0.75 × 0° | −0.375 | +0.16 | −0.03 | −0.98 | −0.38 | — |
| M-LASIK | 36.60 | 17.00 | −0.25 −0.25 × 2° | −0.375 | −0.34 | −0.37 | −1.25 | −1.61 | — |
| M-LASIK | 34.50 | 19.00 | +1.25 −0.50 × 50° | +1.00 | +1.52 | +1.44 | +0.10 | −0.29 | +1.28 |
| M-LASIK | 34.25 | 17.50 | +1.50 −1.25 × 55° | +0.875 | +1.52 | +1.57 | +0.28 | −0.30 | — |
| M-LASIK | 35.75 | 18.00 | −1.0 −0.75 × 0° | −1.375 | +1.30 | +1.45 | +0.13 | +0.04 | +1.395 |
| M-LASIK | 32.00 | 17.00 | −0.25 −0.75 × 40° | −0.625 | +2.15 | +2.39 | +0.78 | +0.43 | — |
| H-LASIK | 47.60 | 21.00 | −1.00 | −1.00 | −0.55 | −0.25 | −0.10 | −0.55 | — |
| H-LASIK | 47.45 | 17.00 | −1.75 −0.50 × 15° | −2.0 | −2.18 | −1.80 | −1.50 | −2.16 | — |
| H-LASIK | 45.75 | 18.00 | −0.50 −0.75 × 167° | −0.875 | −1.02 | −0.81 | −0.58 | −1.38 | +0.71 |
| H-LASIK | 46.28 | 16.50 | +1.50 −0.50 × 10° | +1.25 | −1.14 | −0.99 | −0.85 | −1.67 | −1.22 |
| Mean | 38.91 | 20.11 | | −0.58 | +0.32 | +0.15 | −0.44 | −0.90 | +0.85 |
| SD | 4.05 | 2.79 | | 0.96 | 1.09 | 1.05 | 0.79 | 0.82 | 1.10 |
| Maximum | 47.60 | 28.50 | | +1.25 | +2.62 | +2.55 | +1.68 | +1.05 | +3.46 |
| Minimum | 30.20 | 16.50 | | −3.12 | −2.18 | −1.80 | −1.55 | −2.16 | −0.83 |

*IOL = intraocular lens, difference = final spherical equivalent minus calculated refraction, RK = radial keratotomy, AK = arcuate keratotomy, ALK = automated lamellar keratoplasty, Rpx = retinopexy, PPV = pars-plana vitrectomy, M-PRK = myopic photorefractive keratectomy, M-LASIK = myopic LASIK, H-LASIK = hyperopic LASIK, SD = standard deviation*

TABLE 4

**Calculated Refraction With SRK-T IOL Formula Using the Average of the Orbscan II Central 2-mm Total-mean Power and Achieved Spherical Equivalent Refraction in 77 Eyes With Previous Refractive Surgery That Underwent Uneventful Phacoemulsification in Three Eye Institutions**

| Previous Refractive Surgery | No. of Eyes | Refraction | Mean±SD (D) | Minimum (D) | Maximum (D) | 95% CI | *P* Value |
|---|---|---|---|---|---|---|---|
| RK or RK + AK | 30 | Calculated | −0.57±0.85 | −1.90 | 2.09 | | |
| | | Achieved | −0.51±0.64 | −2.00 | 0.50 | | |
| | | Difference | 0.06±0.86 | −1.97 | 1.50 | −0.38/0.26 | .704 |
| RK + LASIK | 7 | Calculated | −1.41±0.89 | −2.78 | −0.30 | | |
| | | Achieved | −0.38±0.85 | −1.88 | 0.38 | | |
| | | Difference | 1.03±0.93 | −0.38 | 2.62 | 0.26/2.10 | .028 |
| RK + other surgeries | 2 | Calculated | −0.93±0.31 | −1.15 | −0.72 | | |
| | | Achieved | 0.31±0.27 | 0.12 | 0.5 | | |
| | | Difference | 1.25±0.57 | 0.84 | 1.65 | — | .179 |
| M-PRK | 10 | Calculated | −0.53±0.40 | −1.17 | -0.02 | | |
| | | Achieved | −0.50±0.58 | −1.50 | 0.25 | | |
| | | Difference | 0.03±0.68 | −0.89 | 1.05 | −0.47/0.59 | .96 |
| M-LASIK | 22 | Calculated | −0.87±0.85 | −2.78 | −0.04 | | |
| | | Achieved | −0.70±0.96 | −3.12 | 1.0 | | |
| | | Difference | 0.17±0.84 | −0.94 | 2.15 | −0.55/0.20 | .343 |
| H-LASIK | 6 | Calculated | 0.74±1.01 | −0.45 | 2.39 | | |
| | | Achieved | −0.36±1.15 | −2.00 | 1.25 | | |
| | | Difference | −1.10±0.57 | −2.18 | −0.55 | −3.20/−1.10 | .028 |
| All eyes | 77 | Calculated | −0.63±0.92 | −2.78 | 2.39 | −0.84/0.42 | |
| | | Achieved | −0.52±0.79 | −3.12 | 1.25 | −0.70/−0.34 | |
| | | Difference | 0.12±0.93 | −2.18 | 2.62 | −0.09/0.33 | .273 |

*95% CI = 95% confidence interval, RK = radial keratotomy, AK = arcuate keratotomy, M-PRK = myopic photorefractive keratectomy, M-LASIK = myopic LASIK, H-LASIK = hyperopic LASIK, IOL = intraocular lens, calculated refraction = expected refraction with SRK-T formula, achieved refraction = final spherical equivalent achieved, difference = difference between calculated and achieved refraction*

all points or from only the maximum and minimum values inside an assessed zone. Although larger areas with a 4.0- or 4.5-mm diameter have been suggested with this Pentacam's application, a recent study[54] verified that the 2-mm zone would be the best for IOL calculation. This is in agreement with our findings and previous findings using the Orbscan II.[18]

The Galilei (Ziemer Ophthalmic Group, Port, Switzerland) is another topographic system that combines a double Scheimpflug camera with a double Placido ring analysis. This device may show the anterior surface curvature as well as the total corneal powers resultant from the thick lens formula and ray tracing. Similar to the Orbscan II total-optical power,[18,52] the Galilei uses a 4-mm diameter central zone for the total corneal power derived from ray tracing. To assess the anterior curvature and the Gaussian total corneal power, it uses an annular area with 0.5-mm internal radius and 2-mm external radius. The Galilei presently does not use a 2-mm diameter zone for the Gaussian total corneal power. These differences of size and zones shape probably affected the preliminary results on IOL calculation using this device.[55]

By using an adapted thick-lens Gaussian optics formula with values derived from elevation data assessed from a central 5-mm zone of the anterior surface and a 10-mm zone of the posterior surface, Cheng et al[44,49] found that the central 2-mm total-mean postoperative power was 0.74±0.68 D flatter than the keratometric value derived by the clinical history method and that

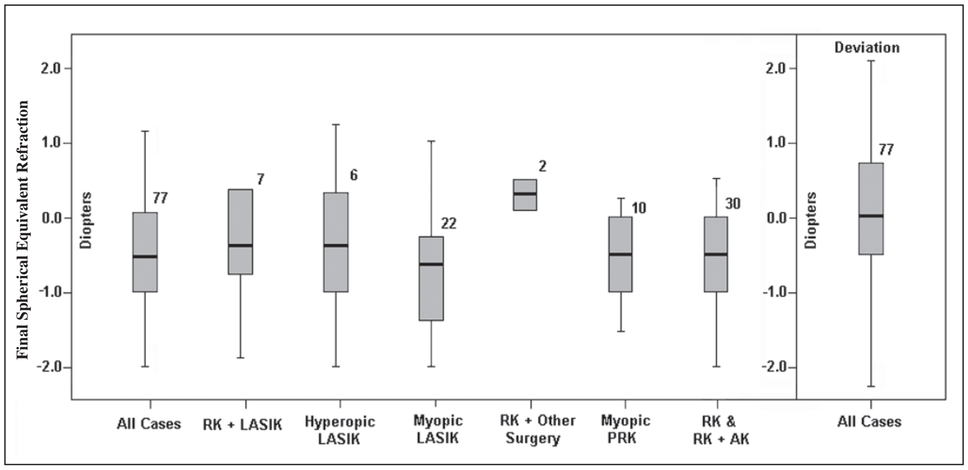


**Figure 2.** Box plot of the final spherical equivalent refraction of all cases and of each group with previous surgery and of the deviation (accuracy) of all cases.

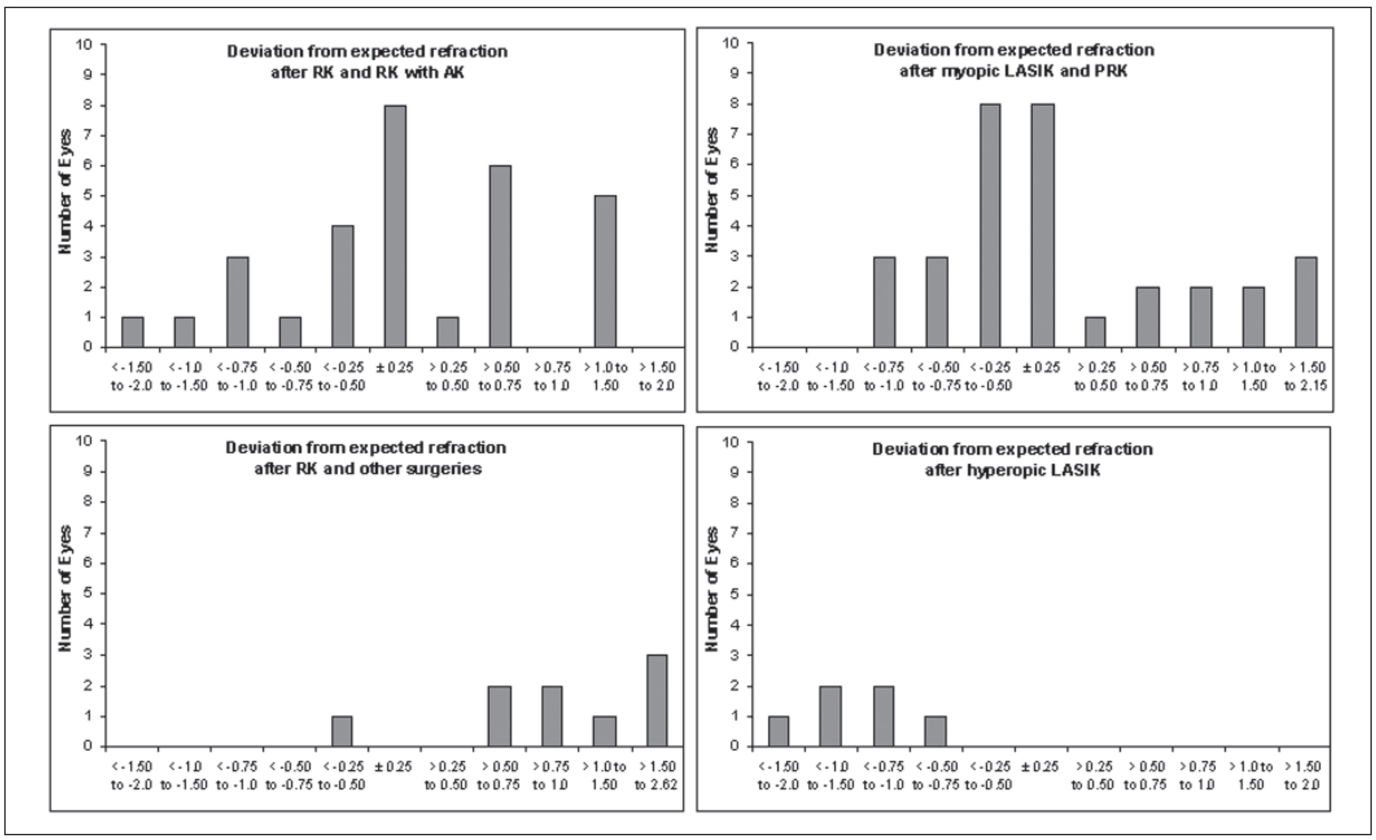


**Figure 3.** Difference between the calculated refraction and achieved spherical equivalent refraction (accuracy) with the SRK-T IOL formula according to previous refractive surgery.

the central 4-mm total-optical power was 0.32±0.77 D steeper. However, from a previous study,[23] it was shown that the Orbscan total-mean power and the equivalent corneal power (thick-lens formula using the thickness, anterior-mean, and posterior-mean curvatures) were not different if both are assessed from central zones with the same size. Therefore, the larger variability found by Cheng et al[44,49] may be due to differences in methods. Furthermore, they calculated the refractive change at the spectacle plane, whereas others[18,23] used the corneal plane because the Orbscan II maps represent powers from the cornea and not from spectacles.

The use of the average value from the 2-mm central zone of Orbscan II total-mean postoperative maps in IOL calculation provided a reasonable postoperative cataract refractive outcome in the absence of reliable data from the previous refractive surgery. The achieved overall spherical equivalent refraction with SRK-T formula was within ±1.50 D in 90% of eyes.

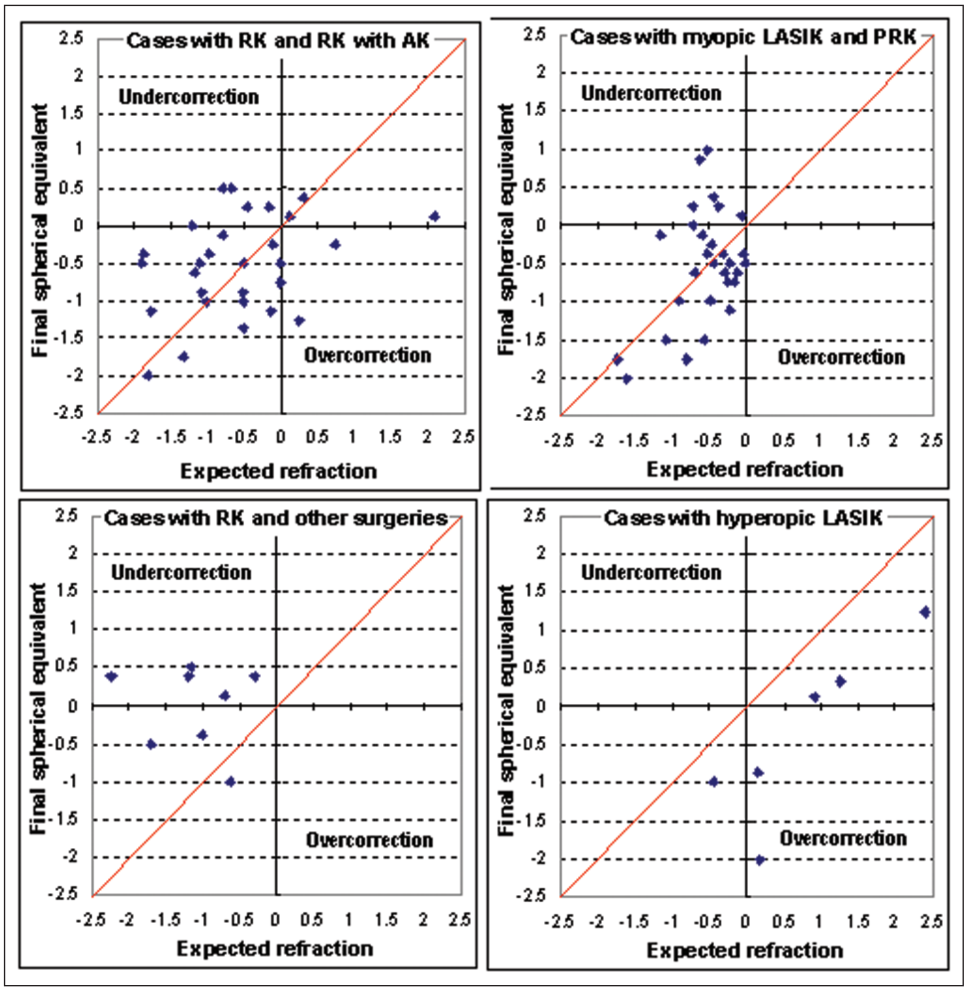


**Figure 4.** Scattergrams of the final achieved spherical equivalent refraction and calculated expected refraction with the SRK-T IOL formula according to previous refractive surgery.

The overall difference between the achieved refraction and the calculated refraction was within ±1.00 D in 77% of eyes with the SRK-T formula, 73% with the Holladay formula, 71% with the Hoffer-Q formula, and 51% with the Haigis formula. Myopic RK, PRK, or LASIK had better results than hyperopic LASIK or RK followed by LASIK and other surgeries. The difference between the achieved refraction and the calculated refraction with the SRK-T formula was within ±1.00 D in 23 (77%) of 30 eyes with RK, and in 27 (90%) of 32 eyes with myopic LASIK or PRK. Even with these reasonably good refractive results, the predictability of this method should be improved especially for eyes with previous myopic PRK. Further study should confirm whether this method is in fact independent of the IOL formula, IOL model, surgeon, and biometric and surgical techniques. The effect of other factors such as corneal astigmatism and thickness before cataract surgery, optimized A constant, location of clear corneal incisions, and effective lens position should also be analyzed in the future.

Our findings suggest that the type of refractive treatment before cataract surgery may affect the predictability of the final refractive result. We did not find a difference between the achieved refractive outcome and the expected refraction in eyes with RK or RK with AK, myopic LASIK, and myopic PRK, but this difference was significant in cases with hyperopic LASIK or RK followed by LASIK. Although eyes with RK and subsequent surgeries seem to trend toward a positive deviation (myopic postoperative cataract refractive error), eyes with hyperopic LASIK seem to trend toward a negative deviation (hyperopic postoperative cataract refractive error). Caution in these complex cases is recommended as more research is needed to understand why they were less accurate. Although not tested in this study, there is a reasonable proposal that the average of the 4-mm total-optical power might be better in cases with hyperopic refractive surgery because it was almost always a little steeper than the 2-mm total-mean power and it will measure part of the paracentral cornea that is treated in hyperopic LASIK or PRK.

Myopic eyes with longer axial lengths can lead to hyperopic refractive errors in IOL calculation.[55,56] A separate analysis[21] with the first 26 eyes (11 eyes with RK, 7 with PRK, and 8 with LASIK) from the New York and Atlanta groups showed that the effect of axial length was V-shape non-linear and significant for the Holladay ($P<.05$) and Hoffer-Q ($P<.005$) formulas but not for the SRK-T formula ($P>.05$). The SRK-T formula had similar accuracy in the three axial length groups studied. The Holladay formula was more accurate for eyes shorter than 26 mm. The Hoffer-Q formula had higher error in eyes between 26 and 27 mm.

As the number of patients who undergo cataract surgery after refractive procedures increases, the need for an accurate method of producing emmetropia in these pseudophakic eyes will grow and will largely depend on the accurate assessment of the corneal power and the IOL calculation formula. Whereas IOL calculation in eyes with refractive surgeries remains challenging due to the difficulties in determining a true total power in modified corneas, biometric errors in eyes with RK, PRK, or LASIK have led to inaccuracies of IOL power.[5-17] The traditional corneal curvature obtained by keratometry has been replaced by an effective refractive power[41] derived from Placido corneal videokeratography. However, this approach tended to underestimate the change after myopic refractive surgery because it uses data from only the anterior surface and an assumed keratometric refractive index.[18] Intraocular lens formulas that assume a single corneal spherical surface miss the oblate anterior surface achieved after myopic refractive surgery and the postoperative modification on the spatial variation of thickness and curvature of both corneal surfaces.

Presently, the typical keratometric value applied in postoperative refractive surgical IOL calculation is the effective corneal power derived by the clinical history method.[11-13] However, because many patients with refractive surgery lack reliable information about their refractive history, numerous methods to determine appropriate values have been devised.[6-18,25-41] Furthermore, the K derived by the history method[11-13] is a value that may still create errors due to a wrong effective lens position derived from incorrectly estimated anterior chamber depth.[36] To solve this problem, it has been suggested to include the keratometric value before refractive surgery (double-K method) in the IOL formulas.[36] Because the history-derived keratometry and the corneal power we used in this study theoretically have equivalent values, the anterior chamber depth variable probably induced a similar error in our cases. Nevertheless, we found that the average of the Orbscan II 2-mm total-mean had a better result than the history-derived keratometry in 8 of 12 eyes. Quantitative area topography is presently being tested to recover the preoperative 2-mm diameter central power that corneas had before undergoing myopic PRK or LASIK directly from the same postoperative total-mean map we used in this study.[58] The aim is to further improve the accuracy of IOL calculation by using a modified double-K method.[36]

Throughout our research we followed the pragmatic thinking that it is better to understand the cause of an error and to avoid it instead of adapting factors to compensate for it. Despite its limitations, this study confirmed that the method developed by Sónego-Krone et al[18] and used to determine the total corneal power directly from eyes with varied refractive surgeries is a valuable tool for IOL calculation.

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**AUTHOR QUERIES**

In the Abstract, Results, please indicate the percentage of eyes with ±0.50 D, and include the range of outcomes for both methods for all eyes.

Please clarify the numbers, as 27/32 is 85%, not 90%
The difference between the achieved refraction and the calculated refraction with the SRK-T formula was within ±1.00 D in 23 (77%) of 30 eyes with RK, and in **27 (90%) of 32 eyes** with myopic LASIK or PRK.

Regarding the references, all parenthetical citations from meetings were added to the reference list per AMA style and all references were renumbered accordingly.

Please verify the authors listed for reference 19, as the authors on PubMed were Jin, Crandall, and Lyle.

Reference 23 could not be found on PubMed. Please verify the authors.

Please verify the title of reference 57. What is meant by "previsibility"? Was the title translated from Portuguese?

Please provide all authors for reference 58.