Accuracy of Scheimpflug Holladay equivalent keratometry readings after corneal refractive surgery

Qiongyan Tang, MD, Kenneth J. Hoffer, MD, Michael D. Olson, OD, PhD, Kevin M. Miller, MD

PURPOSE: To determine the accuracy of Pentacam Scheimpflug system Holladay equivalent keratometry (K) readings (EKRs) in calculating intraocular lens (IOL) power after corneal refractive surgery, including laser in situ keratomileusis (LASIK), photorefractive keratectomy (PRK), and radial keratotomy (RK).

SETTING: Jules Stein Eye Institute, David Geffen School of Medicine at University of California, Los Angeles, Los Angeles, California, USA.

METHODS: In this combined retrospective and prospective clinical study, patients who had cataract surgery after corneal refractive surgery were recalled to have Scheimpflug imaging of the operated cornea and Holladay EKR determination. The Holladay EKR was compared with a gold-standard K value, which was the back-calculated value using the original Hoffer formula based on the actual surgical outcomes. Eyes without a history of refractive surgery served as controls.

RESULTS: Twenty-seven patients (41 eyes) were evaluated; 26 eyes had previous LASIK or PRK and 15, previous RK. Forty-one eyes served as controls. The mean error of the Holladay EKR in eyes with previous LASIK or PRK was +1.84 diopters (D) (range +0.66 to +4.94 D). The mean error in eyes with previous RK was +2.17 D (range +0.48 to +3.09 D). In the control eyes, the mean EKR error was +1.38 D (range −0.17 to +2.54 D).

CONCLUSIONS: The Holladay EKR calculated using version 1.16r04 of the Scheimpflug system software was inaccurate in virgin corneas and in those with a history of LASIK, PRK, or RK using current IOL power calculation formulas. The Scheimpflug power measurements were consistently steeper than the true corneal power.

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Precise intraocular lens (IOL) power calculation after laser in situ keratomileusis (LASIK), photorefractive keratectomy (PRK), and radial keratotomy (RK) is a worldwide challenge for cataract surgeons. The primary problem is obtaining the true corneal or keratometry (K) power after the cornea has been surgically altered. In the setting of previous myopic keratorefractive surgery, eyes usually end up hyperopic after cataract surgery unless specific measures are taken to compensate for surgical changes in corneal curvature. Various methods for K estimation have been developed[1–3]; these include the clinical history method,[4,5] contact lens method,[4,6] vertexed IOL power method,[7] and Ianchulev intraoperative autorefraction method.[8] There are also many methods for adjusting the IOL power calculation to make up for the error in K, such as the Aramberri double-K technique.[9] Although most of these methods improve K estimation accuracy to an extent, postoperative refractive surprises still occur.

The ideal method for measuring corneal K is directly using a device that works independently of refractive surgery information. Standard topography and keratometry are generally accurate in virgin eyes but inaccurate after refractive surgery because they are blind to the center of the cornea and do not measure the contribution of the posterior corneal surface. Most topographers and keratometers also depend on a standard corneal index of refraction that may have been altered by refractive surgery.

The Pentacam (Oculus, Optikgera GmbH) is a rotating single Scheimpflug camera system. It measures anterior and posterior corneal surface elevations and corneal thickness and computes anterior and posterior curvatures to obtain the net corneal power. In the system's software version 1.16r04, the Holladay

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equivalent K reading (EKR) report, developed in cooperation with Jack T. Holladay, MD, uses data from the 4.5 mm optical zone. Theoretically, this Scheimpflug system seems promising for measuring the true corneal power after keratorefractive surgery. The purpose of this study was to determine the accuracy of the system's Holladay EKR in calculating IOL power after LASIK, PRK, and RK.

PATIENTS AND METHODS

After institutional review board approval, consecutive patients who had cataract surgery performed by the same surgeon (K.M.M.) after they had keratorefractive surgery at the Jules Stein Eye Institute or elsewhere were recalled for additional testing. Consecutive patients who had cataract surgery without previous refractive surgery were also recalled to serve as controls.

To be included in the study, patients had to be 21 years or older and have a postoperative corrected distance visual acuity of 20/40 or better so that an accurate postoperative refraction could be obtained. The LASIK and PRK groups were combined in the analysis because the procedures change the anterior cornea without affecting the posterior cornea. In contrast, RK changes both surfaces simultaneously.

Cataract surgery was by phacoemulsification. In most cases, peripheral corneal relaxing incisions were created at the time of cataract surgery. In the practice of the surgeon, a phacoemulsification incision placed on the steep axis is considered to be a relaxing incision. Relaxing incisions reduce or modify astigmatism but have little effect on the spherical equivalent power of the cornea postoperatively.

Patients had 3 tests at the time of the recall visit: (1) Scheimpflug imaging of the operated cornea, (2) manifest refraction in the operated eye using a phoropter and the Jackson cross-cylinder technique, and (3) anterior chamber depth (ACD) measurement using an optical pachymeter (Optical Pachymeter II, Haag-Streit International).[10] The distance from the corneal vertex to the anterior IOL vertex was measured with the pachymeter.

The principal plane of the IOL, also known as the effective lens position (ELP), was computed by adding 50% of the manufacturer-reported central thickness of the implanted IOL to the ACD measured by optical pachymetry. Based on the axial length (AL) measured preoperatively by immersion A-scan ultrasound, the measured ELP, the power of the implanted IOL, and the postoperative refraction, a gold-standard K value was back-calculated for each eye using the original 1974 Hoffer formula[11] (ie, without the Q formula, which manipulates the ACD value.) The mean Holladay EKRs from the Scheimpflug system were compared with

Table 1. Clinical and surgical characteristics of the study patients.

Characteristic	Value
Sex, n (%)	
Female	19 (80.5)
Male	8 (19.5)
Age (y)	
Mean	64.4
Range	37–79
Refractive surgery, n (%)	
Myopic	
LASIK	18 (43.9)
PRK	2 (4.9)
RK	15 (36.6)
Hyperopic	
LASIK	6 (14.6)
Time from refractive surgery to cataract surgery (mo)	
Mean	65.9
Range	23–239
Time from cataract surgery to Scheimpflug measurement (mo)	
Mean	23.8
Range	0.5–70.5

LASIK = laser in situ keratomileusis; PRK = photorefractive keratectomy; RK = radial keratotomy

Table 2. Clinical characteristics of the control patients.

Characteristic	Value
Sex, n (%)	
Female	21 (72.4)
Male	8 (27.6)
Age (y)	
Mean	69.3
Range	50–81
Time from cataract surgery to Scheimpflug measurement (mo)	
Mean	5.0
Range	0.5–35.5

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From the Department of Ophthalmology (Tang, Hoffer, Olson, Miller), David Geffen School of Medicine at UCLA and the Jules Stein Eye Institute, Los Angeles, California, USA; Department of Ophthalmology (Tang), Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China.

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Corresponding author: Kevin M. Miller, MD, Jules Stein Eye Institute, 100 Stein Plaza, UCLA, Los Angeles, California 90095-7002, USA. E-mail: kmiller@ucla.edu.

Table 3. Intraocular lenses implanted in study and control eyes.

IOL Model (Manufacturer)	Center Thickness of 20.0 D IOL (mm)	IOL Design	Study Eyes (n) m-LASIK	h-LASIK	m-PRK	RK	Control Eyes (n)
SA60AT (Alcon)	0.625	Equiconvex	2	2	0	3	1
SN60WF (Alcon)	0.590	Asymmetrically biconvex	3	0	0	0	20
SN60D3 (Alcon)	0.550	Asymmetrically biconvex	0	0	0	0	6
SN6AD3 (Alcon)	0.550	Asymmetrically biconvex	0	0	0	0	11
CC4204BF (Staar)	1.251	Equiconvex	13	3	2	12	3
ZA9003 (Abbott Medical Optics*)	0.959	Asymmetrically biconvex	0	1	0	0	0

h-LASIK = hyperopic laser in situ keratomileusis; IOL = intraocular lens; m-LASIK = myopic laser in situ keratomilsusis; m-PRK = myopic photorefractive keratectomy
*Formerly Advanced Medical Optics

the back-calculated Hoffer formula gold-standard K values using the paired *t* test.

RESULTS

The study group comprised 27 patients (41 eyes); 24 eyes were post-LASIK, 2 were post-PRK, and 15 were post-RK. The control group comprised 29 consecutive patients (41 eyes). Table 1 shows the characteristics of the study group and Table 2, of the control group. All study eyes and more than 90% of control eyes received peripheral corneal relaxing incisions at the time of cataract surgery.

Table 3 shows the IOL models implanted in study eyes and control eyes. All IOLs were biconvex. Equiconvex IOLs were implanted in 90.2% of study eyes and 9.8% of control eyes. Asymmetrically biconvex IOLs were implanted in the remainder of eyes. The accuracy of ELP calculation was greatest in the eyes with an equiconvex IOL. The maximum error can be no greater than lens thickness divided by 2 for the asymmetrically biconvex IOLs.

Table 4 shows the Holladay EKR values, back-calculated true corneal powers, and mean differences. Subtracting the mean back-calculated K value from the mean Holladay EKR in the 26 eyes that had LASIK or PRK showed a difference ranging from +0.66 to +4.94 D. In the 15 eyes that had RK, the difference ranged from +0.48 to +3.09 D. On average, the Scheimpflug system overestimated the true power of the central cornea in study eyes by approximately 2.00 D. Subtracting the mean back-calculated K value from the mean Holladay EKR in the 41 control eyes yielded a difference ranging from −0.17 to +2.54 D. The differences were statistically significant in all subgroups ($P < .001$, paired *t* test).

Figure 1, *A*, shows a plot of the Scheimpflug Holladay EKRs for the post-LASIK and post-PRK eyes versus the back-calculated Hoffer K values. All data in the study eyes fall below the solid line in the figure, indicating overestimation of the true back-calculated corneal power by the Scheimpflug system. Note that as the K readings become steeper, the distance between the lines representing the best-fit linear regression and the perfect correspondence decreases. As the cornea becomes flatter, the Scheimpflug system error increases. Figure 1, *B*, shows a plot of the same data using the Bland-Altman method. Figure 2 shows plots of the data in the 15 post-RK eyes and Figure 3, in the

Table 4. Holladay EKR values, back-calculated true corneal powers, and mean differences.

Group/Subgroup	Number	Mean (D) Holladay EKR	Back-Calculated Corneal Power	Difference	Error Range (D)	*P* Value
Study						
LASIK and PRK	26	41.5	39.7	+1.84	+0.66 to +4.94	<.001
RK	15	39.0	36.9	+2.17	+0.48 to +3.09	<.001
Combined	41	40.6	38.6	+1.96	+0.48 to +4.94	<.001
Control	41	44.2	42.8	+1.38	−0.17 to +2.54	<.001

EKR = equivalent keratometry reading; LASIK = laser in situ keratomileusis; PRK = photorefractive keratectomy; RK = radial keratotomy

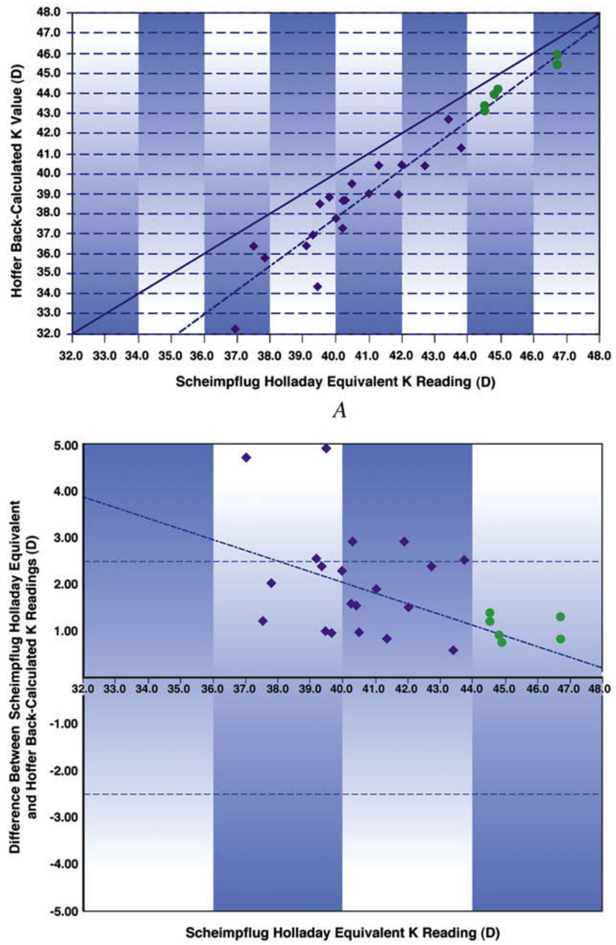

Figure 1. *A*: Pentacam Holladay EKRs versus Hoffer back-calculated K values in 26 eyes with a history of preoperative LASIK or PRK. The diamond-shaped data points represent eyes that had myopic LASIK. The round data points represent eyes that had hyperopic LASIK. The solid line designates perfect correspondence. The dashed line is a best-fit linear regression. *B*: The same data as in *A* shown in a Bland-Altman plot (K = keratometry).

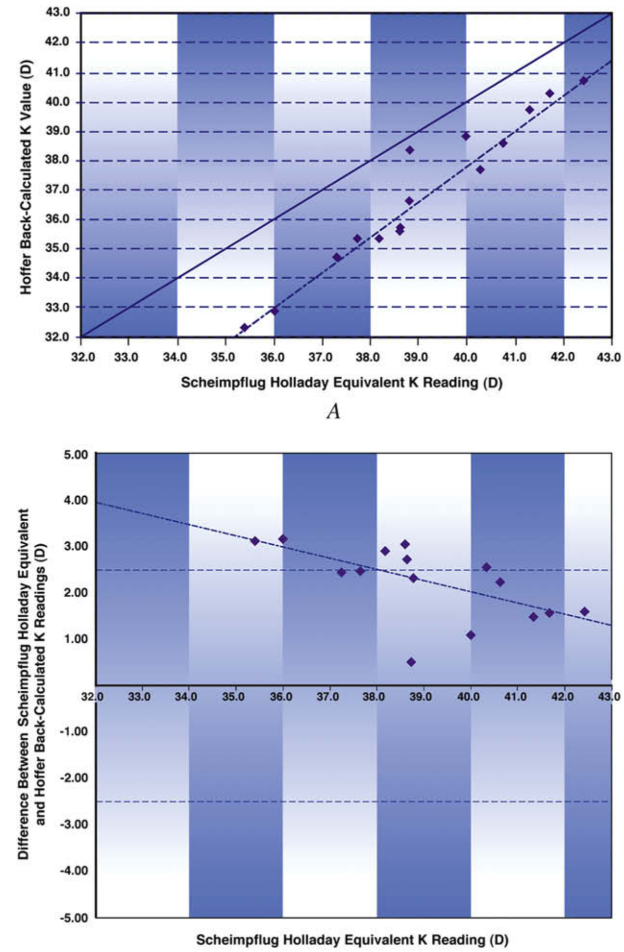

Figure 2. *A*: Pentacam Holladay EKRs versus Hoffer back-calculated K values in the 15 eyes with a history of preoperative RK. The solid line designates perfect correspondence. The dashed line is a best-fit linear regression. *B*: The same data as in *A* shown in a Bland-Altman plot (K = keratometry).

41 control eyes. The Scheimpflug system overestimated the true power of the cornea in all but 1 eye in the control group.

Figure 4 shows a Holladay report from the Scheimpflug system for a post-LASIK eye. The 6 maps show typical post-LASIK findings, including reduced central pachymetry, flattening of central anterior corneal curvature, and normal posterior elevation. The mean EKR (43.8 D) in the 4.5 mm optical zone is displayed in the upper central panel. Figure 5 shows a detailed Holladay report for the same eye.

DISCUSSION

The Pentacam Holladay report software is intended to improve corneal power estimation, especially in eyes that have had keratorefractive surgery. Given currently available IOL power calculation formulas, the measurements it reports are inaccurate.

Lackerbauer et al.[12] found the Pentacam system to be more accurate than keratography in estimating central corneal power after myopic LASIK; however, the authors did not apply their findings to IOL power calculation. Borasio et al.[13] used anterior and posterior curvature and corneal thickness data from the Pentacam system in their BESSt formula and found the approach to be more accurate than several other methods. However, they also found a consistent corneal power error of +1.30 D, similar to our 1.38 D error in control eyes. In their paper, the authors state that "the Gaussian optics formula consistently underestimated corneal values by 1.30 D on average, indicating that either K values measured with corneal topography in virgin eyes overestimate corneal power

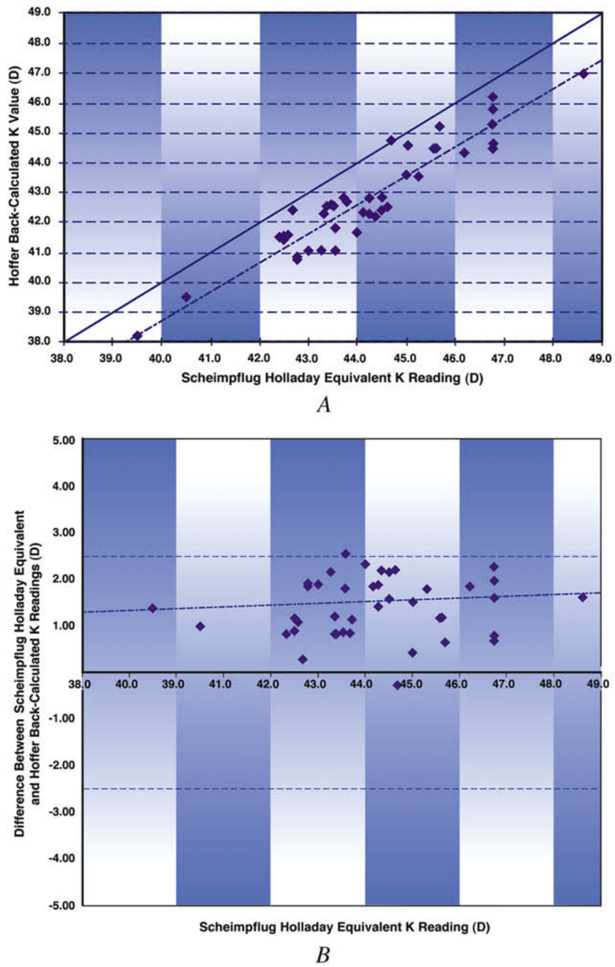

Figure 3. *A*: Pentacam Holladay EKRs versus Hoffer back-calculated K values in the 41 normal control eyes. The solid line designates perfect correspondence. The dashed line is a best-fit linear regression. *B*: The same data as in *A* shown in a Bland-Altman plot (K = keratometry).

by more than 1.00 D or anterior or posterior corneal curvatures measured with the Pentacam are not correct."

In this study, we used the Hoffer back-calculated K value as our gold standard because this formula was developed on the basis of the Gullstrand eye model without altering the ACD in the formula, which is in contrast to other third-generation formulas (Haigis, Hoffer Q, Holladay 1 and 2, and SRK/T). The latter formulas alter or "fudge" the actual ELP and would produce erroneous results if used for this purpose. The optical pachymeter we used to measure ACD in our study was also designed according to the optical principles of the Gullstrand model eye and should theoretically be more accurate than ultrasound or other imaging modalities. Our gold-standard K was back-calculated based on surgical outcomes data, including AL, ELP, implanted IOL power, and postoperative refraction. According to the first-order optics Gullstrand eye model, this back-calculated K value should best reflect true postoperative corneal power.

If the mean +1.38 D error found in the control eyes is used to offset the measurements obtained in the eyes that had previous refractive surgery, sizable relative errors of +0.46 D for post-LASIK and post-PRK eyes and +0.79 D for post-RK eyes continue to be present, indicating that a quick fix to the Pentacam system is not possible. The inaccuracy of the measurements with the Scheimpflug system increased as the change in corneal power induced by keratorefractive surgery increased, as shown by the divergence of the lines in Figures 1 and 2. Conversely, there was little

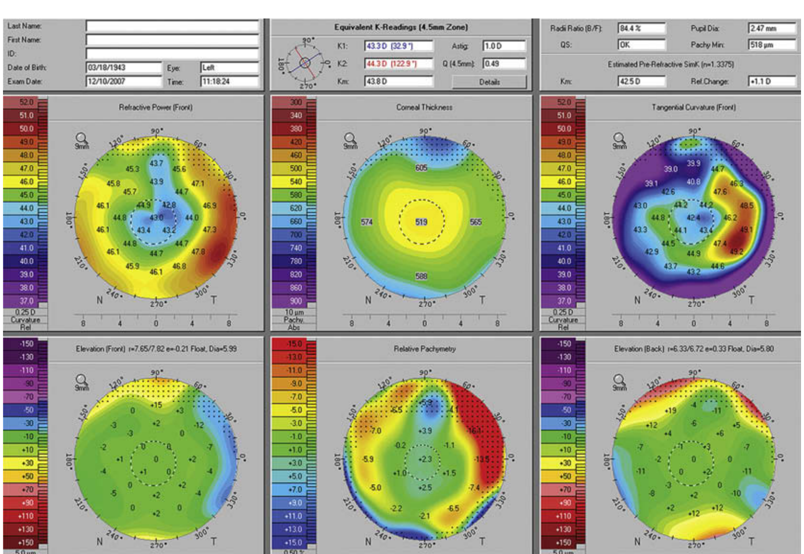

Figure 4. A Scheimpflug system Holladay report for a post-LASIK eye (software version 1.16r04).

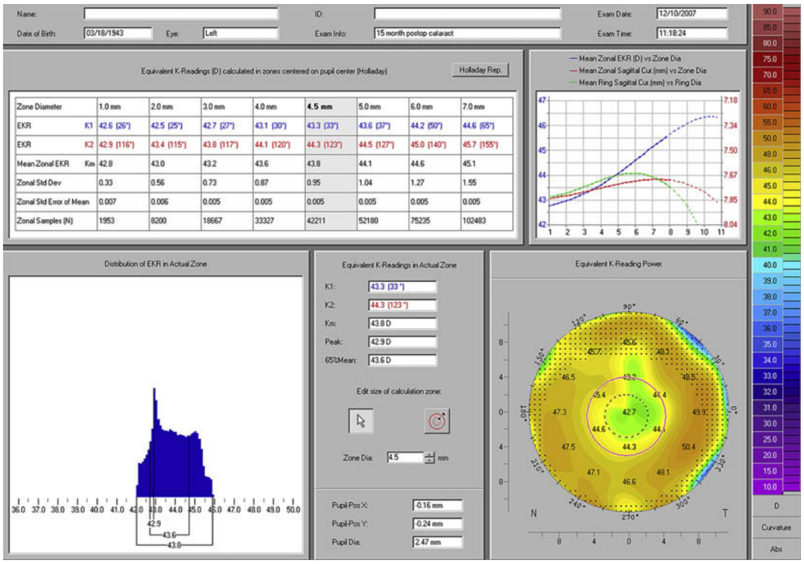

Figure 5. A detailed Holladay report showing additional data for the eye in Figure 4. *Upper left panel*: The EKRs in different optical zones. *Lower left panel*: A histogram of EKR powers in the 4.5 mm zone.

divergence in the lines as a function of corneal steepness or flatness for the virgin corneas (Figure 3, *A*).

In a letter to the editor, Norrby[14] suggested that the "problem" with the Pentacam system might lie in IOL power formulas that use paraxial (thin and thick lens) optics and IOL constants and not with the Scheimpflug system itself. He theorizes that the Scheimpflug measurements may be accurate and that current IOL power calculation formulas may have to be adjusted to accept the system's more accurate K readings. He recommends replacing simple paraxial optics formulas with ray-tracing approaches to improve IOL power calculation.

In summary, our study found that the Holladay EKR, calculated by using version 1.16r04 of the Pentacam software, was inaccurate in virgin corneas and corneas with a history of LASIK, PRK, or RK using current-generation IOL power calculation formulas. The system should be used with caution as a sole instrument for determining corneal power in post-refractive surgery eyes. The Holladay EKR consistently measured a steeper central power than true corneal power based on paraxial optics and surgical outcomes data.

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First author:
Dr. Qiongyan Tang

Department of Ophthalmology, David Geffen School of Medicine at UCLA and the Jules Stein Eye Institute, Los Angeles, California, USA