Validity of the keratometric index: Evaluation by the Pentacam rotating Scheimpflug camera

Jau-Der Ho, MD, PhD, Ching-Yao Tsai, MD, MS, Ray Jui-Fang Tsai, MD,
Li-Lin Kuo, MD, I-Lun Tsai, MD, Shiow-Wen Liou, MD, PhD

PURPOSE: To determine the keratometric index based on actual measurements of the anterior and posterior corneal surfaces using a rotating Scheimpflug camera (Pentacam, Oculus) and evaluate the accuracy of this keratometric index in estimating total and posterior corneal powers.

SETTING: Departments of Ophthalmology, Taipei Medical University Hospital and Taipei City Hospital, Taipei, Taiwan.

METHODS: The right eye of 221 subjects was measured with the Pentacam system. The radius of the best-fit sphere for the anterior corneal surface (r_{ant}) and posterior corneal surface (r_{post}), mean radius of simulated keratometry (r_{simK}), and central corneal thickness were obtained. The ratio of r_{ant} to r_{post} (AP ratio) and keratometric index were calculated in each eye.

RESULTS: The means for r_{ant}, r_{post}, r_{simK}, and AP ratio were 7.75 mm ± 0.28 (SD), 6.34 ± 0.28 mm, 7.75 ± 0.27 mm, and 1.223 ± 0.034 mm, respectively. These parameters were normally distributed. The mean calculated keratometric index (N_{cal}) was 1.3281 ± 0.0018. Using the keratometric indices of 1.3281 (N_{cal}), 1.3315 (Gullstrand schematic eye), and 1.3375 (conventional), the mean arithmetic and absolute estimation errors for the total corneal power were, 0.00 ± 0.24 diopter (D) and 0.17 ± 0.17 D, 0.43 ± 0.23 D and 0.45 ± 0.21 D, and 1.21 ± 0.24 D and 1.21 ± 0.24 D, respectively. The total corneal power was predicted to within ±0.50 D of the actual value in 95.0%, 60.2%, and 0.9% of eyes, respectively. The mean arithmetic and absolute estimation errors for the posterior corneal power using an AP ratio of 1.223 (this study) or 1.132 (Gullstrand schematic eye) were 0.00 ± 0.17 D and 0.13 ± 0.12 D and 0.47 ± 0.18 D and 0.47 ± 0.17 D, respectively. The posterior corneal power was estimated to within ±0.50 D of the actual value in 97.7% and 60.2% of eyes, respectively.

CONCLUSION: Using the Pentacam-derived keratometric index improved the prediction accuracies of total and posterior corneal powers.

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Both the anterior and posterior corneal surfaces contribute to the total corneal refractive power. However, total corneal power is usually solely derived clinically from the keratometer-measured anterior corneal radius. This mathematical shortcut is used due to difficulties in measuring the posterior corneal surface in clinical settings, especially in the past. The keratometric index was developed so the omission of the posterior corneal surface measurement could be compensated for by measuring only the anterior corneal surface.[1,2] For this algorithm to be valid, the anterior and posterior corneal curvatures are presumed to have a constant and linear relationship.[3] The commonly used keratometric indices include 1.3375, which is built into many keratometers,[1,4] and 1.3315, which is derived from the Gullstrand schematic eye[5] and independently recommended by Olsen.[2]

In various schematic eyes, the ratio of the radius of the anterior corneal curvature to the radius of the posterior corneal curvature (AP ratio) ranged from 1.132 (Gullstrand schematic eye) to 1.2 (Le Grand full theoretical eye, Lotmar finite schematic eye, Kooijman finite schematic eye).[6,7] The AP ratio in real eyes has been evaluated in several studies. The studies used techniques such as slitlamp photography, Purkinje imagery, pachymetry, photokeratoscopy, corneal topography, Scheimpflug photography, and slit-scan topography. Table 1 summarizes the methods and results in these studies, which found an average AP ratio ranging from 1.177 to 1.235.[3,8–15] Most studies calculated the AP ratio in 1 or several fixed meridians.[8–14]

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Table 1. Comparison of the AP ratio in different studies.

Study*	Measurement Method	Measured Site	AP Ratio
Lowe[8]	Slitlamp photography	Vertical meridian	1.184
Royston[9]	Purkinje imagery and pachymetry	3 fixed meridians	1.215
Royston[10]	Slitlamp	Vertical meridian	1.223
Royston[10]	Purkinje imagery	Vertical meridian	1.214
Edmund[11]	Photokeratoscopy and pachymetry	Horizontal meridian	1.177
Garner[12]	Purkinje imagery	Vertical meridian	1.210 ± 0.045
Dubbelman[13]	Scheimpflug photography	Vertical meridian	1.235
Dubbelman[14]	Scheimpflug photography	6 fixed meridians	1.190
Lim[15] and Fam[3]	Slit-scan topography	Whole cornea	1.22 ± 0.03

AP ratio = ratio of the radius of the anterior corneal curvature to the radius of the posterior corneal curvature
*First author

Only 2 studies (by the same group of authors[3,15]) used the best-fit sphere (BFS) of the corneal elevation map, which is obtained by the Orbscan II (Bausch & Lomb) to summarize the data from all meridians to calculate the AP ratio. This might be because until recent years, only the Orbscan could measure a large number of data points (9000 data points) over both the anterior and posterior surfaces of the entire cornea in a very short time (1.5 seconds).[16] The accuracy of the Orbscan for posterior corneal curvature measurement has not been fully validated.[17,18] It has also been criticized as measuring the posterior corneal surface inaccurately in eyes after keratorefractive surgery.[18–21]

The Pentacam (Oculus) uses a rotating Scheimpflug camera to image the anterior segment. It provides elevation maps of the anterior and posterior corneal surfaces, pachymetry maps, and biometric measurements of the anterior segment.[22,23] It measures 25 000 data points over the cornea in fewer than 2 seconds.[24] In a study comparing the central corneal thickness measurement with the Pentacam, Orbscan, and ultrasound (with Pentacam and Orbscan, measurement of anterior and posterior corneal surface elevations must be used for corneal thickness determination), the Pentacam showed the best interobserver reproducibility of all modalities. The Pentacam-measured central corneal thickness values were also closer to the ultrasound pachymetry-measured values and showed less variability than those obtained with the Orbscan.[25] The intensity profiles also showed a steeper corneal edge depiction with the Pentacam than with the Orbscan II. Therefore, the Pentacam may have a less blurred corneal edge, which might result in fewer detection errors than with the Orbscan II.[25] In eyes after uneventful laser in situ keratomileusis or photorefractive keratectomy, the Pentacam did not show the apparent ectasia in the posterior corneal surface that was commonly shown by the Orbscan, and this has been strongly suspected of not being a true physical phenomenon.[21,26]

In this study, we used the Pentacam device to measure the anterior and posterior corneal surface elevations. The radius of the BFS was determined for both the anterior and posterior corneal surfaces. The AP ratio and keratometric index were then calculated, and their accuracies in estimating the posterior and total corneal powers were evaluated.

SUBJECTS AND METHODS

Subjects were randomly selected from the ophthalmology clinic of Taipei City Hospital. All subjects provided informed consent. Those who had corneal or retinal disease or previous ocular surgery were excluded. Subjects who had worn contact lenses at any time 1 month before the examination were also excluded. All subjects had a full ophthalmic examination. The data were collected from the right eye of the subjects. All data acquisition with the Pentacam was performed by trained examiners. Subjects were asked to fully blink just before each measurement with the Pentacam to spread an optically smooth tear film over the cornea.

The elevation maps of the anterior and posterior corneal surfaces over the central 4.0 mm were fitted with reference to the BFS by the software of the Pentacam.[15] The radii of

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From the Departments of Ophthalmology, Taipei Medical University Hospital (Ho), Taipei Medical University (Ho, R.J.-F. Tsai, Liou), Taipei City Hospital (C.-Y. Tsai, Kuo, I.L, Tsai, Liou), and National Taiwan University Hospital (Liou); and the Community Medicine Research Center and Institute of Public Health (C.-Y. Tsai), National Yang-Ming University, Taipei, Taiwan.

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Corresponding author: Shiow-Wen Liou, MD, PhD, Department of Ophthalmology, Taipei City Hospital, 145 Zheng Zhou Road, Taipei 103, Taiwan. E-mail: swan@tpech.gov.tw.

the BFS in the central 4.0 mm for the anterior corneal elevation (r_{ant}) and posterior corneal elevation (r_{post}) was obtained for each eye. The mean radius of curvature of the simulated keratometry shown by the Pentacam was designated r_{simK}. According to the user's manual, simulated keratometry was based on the data on the 3.0 mm ring. Central corneal thickness was also measured by the Pentacam. The AP ratio in each eye was computed as follows:

$$\text{AP ratio} = \frac{r_{ant}}{r_{post}} \tag{1}$$

The mean of the AP ratio in each eye in this study was then calculated (AP_{cal}). The actual total corneal power in the central 4.0 mm (P_{actual}) was calculated using the Gaussian optics formula as follows:

$$P_{actual} = \frac{n_c - 1}{r_{ant}} + \frac{n_a - n_c}{r_{post}} - \frac{d}{n_c} \times \left(\frac{n_c - 1}{r_{ant}}\right) \times \left(\frac{n_a - n_c}{r_{post}}\right) \tag{2}$$

where n_c (1.376) and n_a (1.336) are the refractive indices for the cornea and aqueous, respectively, and d is the central corneal thickness. For calculating the true keratometric index (n_{cal}) in each eye, the following equation was used:

$$\frac{n_{cal} - 1}{r_{simK}} = P_{actual} \tag{3}$$

The mean of n_{cal} in each eye was calculated and designated N_{cal}; N_{cal} was then used to calculate the estimated total corneal power (P_{cal}) in each eye as follows:

$$P_{cal} = \frac{N_{cal} - 1}{r_{simK}} \tag{4}$$

The total corneal power estimation error with this newly derived keratometric index was calculated by

$$\text{Total corneal power estimation error} = P_{cal} - P_{actual}$$

The estimated total corneal power using the keratometric index derived from the Gullstrand schematic eye (1.3315) was calculated by

$$P_{Gullstrand} = \frac{1.3315 - 1}{r_{simK}} \tag{5}$$

Similarly, the total corneal power estimation error with the keratometric index of 1.3315 was calculated by ($P_{Gullstrand} - P_{actual}$).

The estimated total corneal power using the conventional keratometric index (1.3375) was calculated by

$$P_{conv} = \frac{1.3315 - 1}{r_{simK}} \tag{6}$$

The total corneal power estimation error with the keratometric index of 1.3375 was calculated by ($P_{conv} - P_{actual}$).

The performances of different keratometric indices (N_{cal}, 1.3315, and 1.3375) in estimating the total corneal power were evaluated by the following criteria[27]:

1. mean arithmetic total corneal power estimation error
2. mean absolute total corneal power estimation error
3. variance of the mean arithmetic total corneal power estimation error (smaller variance indicates better consistency of estimation performance)
4. percentage of eyes within certain range (eg, ±0.5 diopters [D]) of estimation error.

The mean arithmetic estimation errors for total corneal power produced with different keratometric indices were compared using the paired *t* test. Variances of the mean arithmetic estimation error were tested using the *F* test for variance. A *P* value less than 0.05 was considered statistically significant. For statistical evaluation, SPSS for Windows (version 13.0, SPSS, Inc.) was used.

For evaluation of the posterior corneal power estimation, the actual posterior corneal power ($PostP_{actual}$) was computed by

$$PostP_{actual} = \frac{n_a - n_c}{r_{post}} \tag{7}$$

Assuming that the posterior corneal power could not be measured directly, the posterior corneal power could be estimated based on the mean AP ratio (AP_{cal}) obtained in this study by

$$PostP_{cal} = \frac{n_a - n_c}{r_{simK}/AP_{cal}} \tag{8}$$

The AP ratio derived from the Gullstrand schematic eye ($7.7/6.8 = 1.132$) was also used to estimate the posterior corneal power by

$$PostP_{cal} = \frac{n_a - n_c}{r_{simK}/1.132} \tag{9}$$

The performances of different AP ratios (AP_{cal} and $AP_{Gullstand} = 1.132$) in estimating the posterior corneal power were similarly evaluated by the above-described criteria.

RESULTS

This study comprised right eyes of 114 men and 107 women. The mean age of the subjects was 44.6 years ± 19.0 (SD) (range 15 to 86 years). The mean spherical equivalent in the eyes was −2.01 ± 3.47 D (range −18.375 to +6.375 D). Table 2 shows the corneal parameters. With the exception of n_{cal} ($P = .047$, Kolmogorov-Smirnov test), all other corneal parameters conformed to a normal distribution ($P > .05$, Kolmogorov-Smirnov test). The distributions of the AP

Table 2. Summary of corneal parameters.

Parameter	Mean ± SD	Range	*P* Value*
r_{ant} (mm)	7.75 ± 0.28	7.06–8.49	.782
r_{post} (mm)	6.34 ± 0.28	5.62–7.00	.970
r_{simK} (mm)	7.75 ± 0.27	7.05–8.46	.905
AP ratio	1.223 ± 0.034	1.086–1.391	.299
Pachymetry (μm)	567.8 ± 36.0	450–684	.251
n_{cal}	1.3281 ± 0.0018	1.3209–1.3363	.047

AP ratio = ratio of the radius of the best-fit sphere for the anterior corneal elevation to the radius of the best-fit sphere for the posterior corneal elevation in the central 4.0 mm; n_{cal} = calculated keratometric index based on the Gaussian paraxial power; r_{ant} = radius of the best-fit sphere for the anterior corneal elevation in the central 4.0 mm; r_{post} = radius of the best-fit sphere for the posterior corneal elevation in the central 4.0 mm; r_{simK} = mean radius of the simulated keratometry
*Kolmogorov-Smirnov test

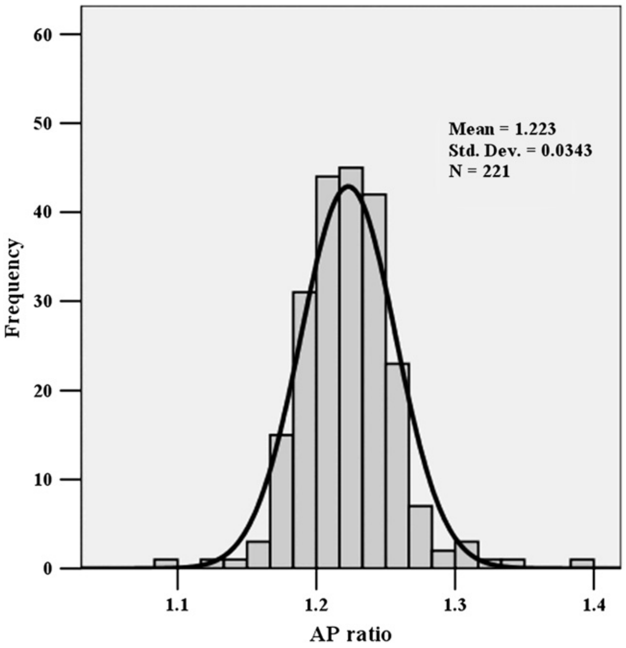

Figure 1. The distribution of the AP ratio (the ratio of the radius of the BFS for the anterior corneal elevation to the radius of the BFS for the posterior corneal elevation in the central 4.0 mm). The AP ratio conforms to a normal distribution (*P* = .299, Kolmogorov-Smirnov test).

ratio and n_{cal} are shown in Figure 1 and Figure 2, respectively.

Linear regression revealed that r_{ant} was correlated with r_{post}. The regression equation was r_{post} =

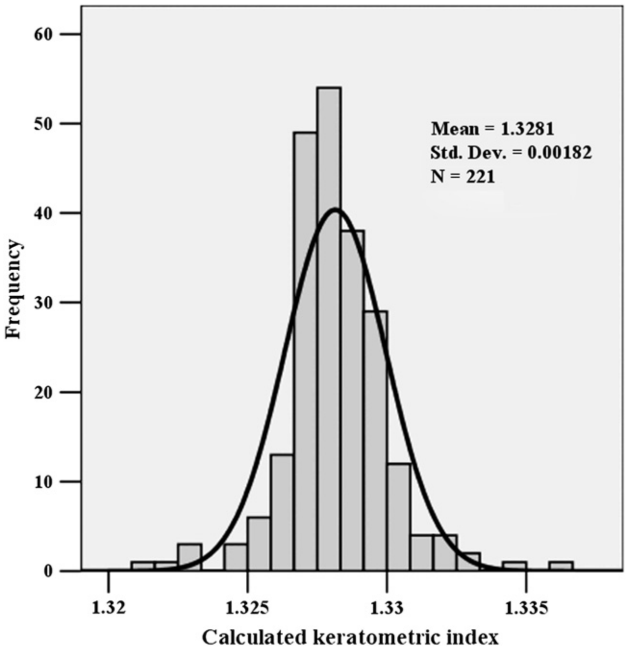

Figure 2. The distribution of the calculated keratometric index (n_{cal}). The calculated keratometric index was not normally distributed (*P* = .047, Kolmogorov-Smirnov test).

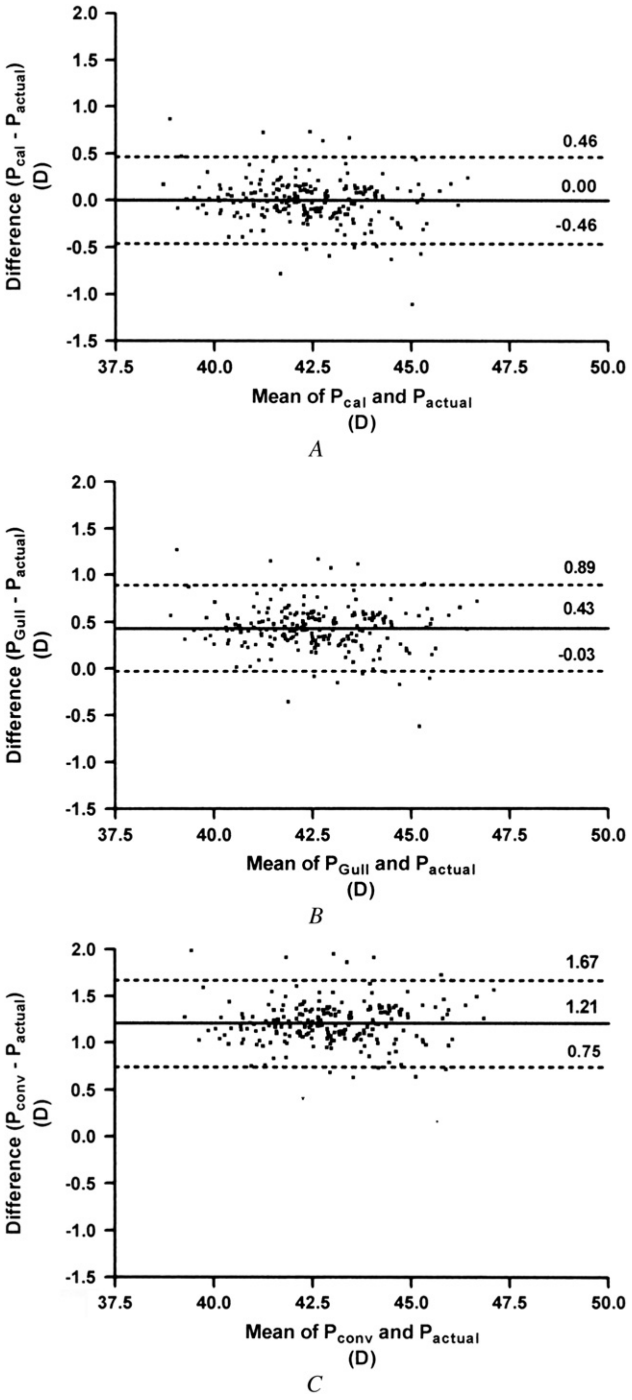

Figure 3. Bland-Altman plots comparing the total corneal powers calculated with different keratometric indices and the actual total corneal power derived from the Gaussian optics formula (P_{actual}). Mean differences are represented by solid lines, and 95% LoA are represented by dotted lines. *A*: Comparison between P_{cal} (total corneal power calculated with the mean keratometric index of 1.3281 derived in this study) and P_{actual}. *B*: Comparison between P_{Gull} (total corneal power calculated with the keratometric index of 1.3315 derived from the Gullstrand schematic eye) and P_{actual}. *C*: Comparison between P_{conv} (total corneal power calculated with the conventional keratometric index of 1.3375) and P_{actual}.

$0.781r_{ant} + 0.293$ ($r = 0.776$, $P < .0001$); r_{simK} was also correlated with r_{ant} and r_{post}. The regression equations were $r_{ant} = 1.006r_{simK} - 0.048$ ($r = 0.996$, $P < .0001$) and $r_{psot} = 0.793r_{simK} + 0.194$ ($r = 0.781$, $P < .0001$). The mean AP ratio (AP_{cal}) was 1.223 ± 0.034 (range 1.086 to 1.391). The mean keratometric index (N_{cal}) was 1.3281 ± 0.0018 (range 1.3209 to 1.3363).

Figure 3 shows the Bland-Altman plots comparing the total corneal powers calculated with different keratometric indices (P_{cal}, P_{Gull}, and P_{conv}) and the actual total corneal power derived from the Gaussian optics formula (P_{actual}).The 95% limits of agreement (95% LoA) for P_{cal} versus P_{actual}, P_{Gull} versus P_{actual}, and P_{conv} versus P_{actual} were −0.46 to 0.46 D, −0.03 to 0.89 D, and 0.75 to 1.67 D, respectively. The mean values for the Gaussian paraxial power of the cornea (P_{actual}) and the calculated total corneal powers of P_{cal}, $P_{Gullstrand}$, and P_{conv} are shown in Table 3. The estimation results for the total corneal power with different keratometric indices are also summarized in Table 3. The mean arithmetic and absolute estimation errors of P_{cal} (with a keratometric index of 1.3281 derived in this study) for the total corneal power were 0.00 ± 0.24 D and 0.17 ± 0.17 D, respectively. There was no significant difference between P_{cal} and P_{actual} ($P = .964$, paired t test). Of these eyes, 95.0% (210 eyes) had a P_{cal} within ±0.50 D of P_{actual}. The mean arithmetic and absolute estimation errors of $P_{Gullstrand}$ (with a keratometric index of 1.3315) for the total corneal power were 0.43 ± 0.23 D and 0.45 ± 0.21 D, respectively. There was a significant difference between $P_{Gullstrand}$ and P_{actual} ($P < .0001$, paired t test). The mean arithmetic estimation error with the keratometric index of the Gullstrand schematic eye (1.3315) was significantly different from the mean arithmetic estimation error produced by the calculated keratometric index (1.3281) ($P < .0001$, paired t test). Of these eyes, 60.2% (133 eyes) had a $P_{Gullstrand}$ that was within ±0.50 D of P_{actual}. The mean arithmetic and absolute estimation errors of P_{conv} (with a keratometric index of 1.3375) for the total corneal power were 1.21 ± 0.24 D and 1.21 ± 0.24 D, respectively. The difference between P_{conv} and P_{actual} was statistically significant ($P < .0001$, paired t test). The mean arithmetic estimation error with the conventional keratometric index (1.3375) was significantly different from the mean arithmetic estimation error produced by our calculated keratometric index (1.3281) ($P < .0001$, paired t test). Of these eyes, 0.9% (2 eyes) had a P_{conv} that was within ±0.50 D of P_{actual}. The variances of the mean arithmetic estimation error of P_{cal}, $P_{Gullstrand}$, and P_{conv} did not significantly differ from each other (all $P > .05$, F test).

Figure 4 shows the Bland-Altman plots comparing the posterior corneal powers calculated with different AP ratios ($PostP_{cal}$, $PostP_{Gull}$) and the actual posterior corneal power ($PostP_{actual}$). The 95% LoA for $PostP_{cal}$ versus $PostP_{actual}$, and $PostP_{Gull}$ versus $PostP_{actual}$ are −0.34 to 0.34 D, and 0.13 to 0.81 D, respectively. The mean values of $PostP_{actual}$, $PostP_{cal}$, and $PostP_{Gullstrand}$ are shown in Table 4. The estimation results of $PostP_{cal}$ and $PostP_{Gullstrand}$ for the posterior corneal power are also shown in Table 4. When the mean AP ratio derived from this study (1.223) was used, the mean arithmetic and absolute estimation errors for the posterior corneal power were 0.00 ± 0.17 and 0.13 ± 0.12 D, respectively. There was no significant difference between $PostP_{cal}$ and $PostP_{actual}$ ($P = .912$, paired t test). Of these eyes, 97.7% (216 eyes) had a $PostP_{cal}$ with an estimation error within ±0.50 D. When the AP ratio of 1.132 (from the Gullstrand schematic eye) was used, the mean arithmetic and absolute estimation errors for the posterior corneal power were 0.47 ± 0.18 D and 0.47 ± 0.17 D, respectively. There was

Table 3. Mean values for the total corneal power calculated with different keratometric indices; the mean and absolute estimation errors from the actual total corneal power (P_{actual}) and the percentage of eyes within ±0.50 D of estimation error.

Parameter	P_{actual}	P_{cal}	$P_{Gullstrand}$	P_{conv}
Total corneal power (D)				
Mean ± SD	42.38 ± 1.54	42.38 ± 1.50	42.81 ± 1.52	43.59 ± 1.55
Range	38.43 to 46.30	38.79 to 46.55	39.18 to 47.02	39.89 to 47.87
Estimation error for total corneal power (D)				
Mean ME ±SD	—	0.00 ± 0.24	0.43 ± 0.23	1.21 ± 0.24
Error range	—	−1.10 to 0.87	−0.64 to 1.27	0.17 to 1.99
Within ±0.50 D (%)	—	95.0	60.2	0.9
Mean MAE ± SD	—	0.17 ± 0.17	0.45 ± 0.21	1.21 ± 0.24
Error range	—	0.00 to 1.10	0.00 to 1.27	0.17 to 1.99

MAE = mean absolute estimation error; ME = mean arithmetic estimation error; P_{actual} = actual total corneal power with Gaussian paraxial optics formula; P_{cal} = total corneal power calculated with the mean keratometric index derived in this study (1.3281); P_{conv} = total corneal power calculated with the conventional keratometric index of 1.3375; $P_{Gullstrand}$ = total corneal power calculated with the keratometric index derived from the Gullstrand schematic eye (1.3315)

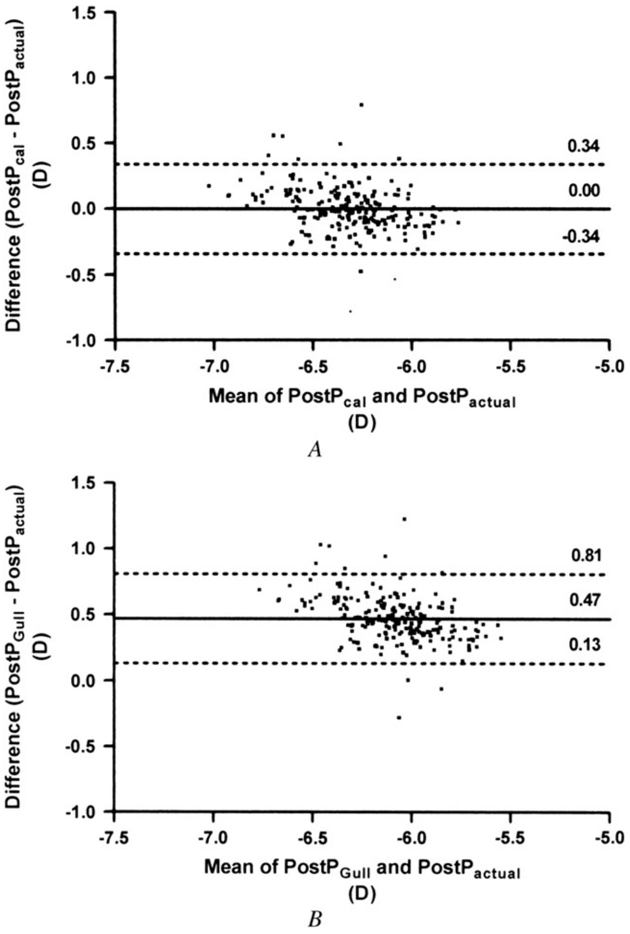

Figure 4. Bland-Altman plots comparing the posterior corneal powers calculated with different AP ratios and the actual posterior corneal power (PostP$_{actual}$). Mean differences are represented by solid lines and 95% LoA are represented by dotted lines. *A*: Comparison between PostP$_{cal}$ (posterior corneal power calculated with the AP ratio of 1.223 derived in this study) and PostP$_{actual}$. *B*: Comparison between PostP$_{Gull}$ (posterior corneal power calculated with the AP ratio of 1.132 derived from the Gullstrand schematic eye) and PostP$_{actual}$.

a significant difference between PostP$_{Gullstrand}$ and PostP$_{actual}$ ($P < .0001$, paired *t* test). The mean arithmetic estimation error for the posterior corneal power produced by the AP ratio of the Gullstrand schematic eye (1.132) was significantly different from the mean arithmetic estimation error produced by our calculated AP ratio (1.223) ($P < .0001$, paired *t* test). Of these eyes, 60.2% (133 eyes) had a PostP$_{Gullstrand}$ with an estimation error within ±0.50 D. There was no significant difference between the variances of the mean arithmetic estimation error of PostP$_{cal}$ and PostP$_{Gullstrand}$ ($P > .05$, *F* test).

DISCUSSION

In this study, we used a rotating Scheimpflug camera (the Pentacam) to measure the anterior and posterior corneal surfaces and corneal thickness. The data were then used to derive the mean AP ratio and the mean calculated keratometric index. We showed that using the mean AP ratio (1.223) and the keratometric index (1.3281) developed in this study would provide a good estimation of the posterior corneal power and total corneal power without measuring the posterior corneal surface or corneal thickness. Performing calculations with the keratometric index of 1.3281 derived from this study enhanced the accuracy of the total corneal power estimation in comparison with the keratometric index of 1.3315 of the Gullstrand schematic eye and the most commonly used keratometric index value of 1.3375.

In studies that determined the keratometric index based on actually measured corneal parameters, Dubbelman et al.[14] calculated a keratometric index of 1.329 ± 0.001 in 114 eyes with corrected Scheimpflug images that were measured in the central 7.5 mm and in 6 fixed meridians. Dunne et al.[28] determined a keratometric index of 1.3283 in 80 eyes based on Purkinje

Table 4. Mean values for the posterior corneal power calculated with different AP ratios; the mean and absolute estimation errors from the actual posterior corneal power (PostP$_{actual}$) and the percentage of eyes within ±0.50 D of estimation error.

Parameter	PostP$_{actual}$	PostP$_{cal}$	PostP$_{Gullstrand}$
Posterior corneal power (D)			
Mean ± SD	−6.32 ± 0.28	−6.32 ± 0.22	−5.85 ± 0.21
Range	−7.12 to −5.71	−6.94 to −5.78	−6.42 to −5.35
Estimation error for posterior corneal power (D)			
Mean ME ± SD	—	0.00 ± 0.17	0.47 ± 0.18
Error range	—	−0.78 to 0.80	−0.28 to 1.23
Within ±0.50 D (%)	—	97.7	60.2
Mean MAE ± SD	—	0.13 ± 0.12	0.47 ± 0.17
Error range	—	0.00 to 1.80	0.01 to 1.23

MAE = mean absolute estimation error; ME = mean arithmetic estimation error; PostP$_{actual}$ = actual posterior corneal power calculated with equation 7; PostP$_{cal}$ = posterior corneal power calculated with the AP ratio derived in this study (1.223); PostP$_{Gullstrand}$ = posterior corneal power calculated with the AP ratio derived from the Gullstrand schematic eye (1.132) images and pachymetry measured in 3 meridians. Fam and Lim[3] used scanning-slit videokeratography (Orbscan II) to measure central corneal thickness and the radii of the BFS aligned to the anterior and posterior corneal elevations generated from the full corneal diameter in 2429 eyes. They determined a keratometric index of 1.3273 ± 0.0013. In their study, the zone size for measurement of BFS was not standardized to a particular diameter in each eye but to the full corneal diameter measured by the Orbscan II. In our study, we chose the central 4.0 mm as the zone for determining the radii of the BFS for the anterior and posterior corneal surfaces and thus the total corneal power because the central 4.0 mm represents a region where the cornea is essentially spherical and can be represented by paraxial power. According to a study by Holladay, the 4.0 mm zone had the best agreement of the measured corneal power with the calculated corneal power. Sampling a zone smaller than 4.0 mm excludes too much of the pupil through which the rays are passing (J.T. Holladay, MD, "Measuring Corneal Power after Corneal Refractive Surgery; How the Pentacam Improves the Accuracy of These Calculations," In: Why Cataract and Refractive Surgeons Need the Pentacam. Insert to Cataract Refract Surg Today Jan 2006; 4–6. Available at: http://www.oculus.de/en/downloads/dyn/sonstige/sonstige/press_cataract_pentacam_0206pdf. Accessed October 8, 2007).

Zones larger than 5.0 mm are likely to be affected by corneal asphericity. Because the cornea tends to flatten in the periphery, the BFS would tend to have a longer radius for large zone sizes. Therefore, our result might be more representative of the central corneal power and more significant in terms of clinical optics. We also performed the measurements in zones of different diameters. The resultant keratometric indices were 1.3278 ± 0.0027, 1.3284 ± 0.0021, 1.3284 ± 0.0031, 1.3280 ± 0.0038, and 1.3277 ± 0.0042 for the central 3.0, 5.0, 6.0, 7.0, and 7.5 mm zones, respectively.

The mean keratometric index in our study (1.3281 ± 0.0018) was significantly different from the mean (1.3273 ± 0.0013) derived in the Fam and Lim study,[3] in which the Orbscan II was used ($P<.001$, 2-sample *t* test). The possible causes of this difference included the difference in the instruments used (Pentacam versus Orbscan) and the difference in zone sizes based on which the BFS was aligned, as mentioned above. Another possible cause of the difference in the mean keratometric indices is the difference in age distribution of subjects between the 2 studies. In Fam and Lim's study, subjects were composed of refractive surgery candidates and the mean age was 32.63 ± 9.35 years (range 15.3 to 59 years). In our study, we chose subjects from a hospital-based ophthalmology clinic and the age distribution was wider. The mean age was 44.6 ± 19.0 years (range 15 to 86 years). The distribution in ethnicity was not mentioned in Fam and Lim's study. However, in their previous study of subjects from the same laser center in Singapore,[15] most subjects (82%) were ethnic Chinese and more than 90% were Asian. In our study, all subjects were ethnic Chinese. Therefore, a difference in ethnicity may not be responsible for the difference in the mean keratometric indices between the studies.

One limitation in our study was that we used a fixed zone size (central 4.0 mm diameter) to calculate the keratometric index. We did not analyze the elevation data according to the entrance pupil. An analysis that considered the entrance pupil and/or Stiles-Crawford effect might have increased the accuracy of the computed keratometric index from the viewpoint of clinical optics. In this study, we chose the corneal thickness at the pupil center as the value for d in equation 2. The most optically correct would be the corneal thickness along the line of sight. This will be difficult to extract from the data because the Pentacam does not show the location on the cornea that intersects with the line of sight. The central pachymetry is easy to obtain on the Pentacam and is approximate to the location on the cornea that intersects with the line of sight, although this may be different especially if the pupil is decentered.

Another limitation of this study is the concern that the accuracy of the Pentacam in corneal thickness measurement has not been validated. Previous studies[25,29–32] report that the 95% LoA between the Pentacam and ultrasound pachymetry are in the range of −36.74 to 49.68 μm. Using the Gaussian optics formula in equation 2 and the corneal parameter data of the 221 eyes in our study, we found that even a corneal thickness measurement error as large as 100 μm (which should happen extremely rarely as concluded from the previous studies[25,29–32]) would be associated with a mean total corneal power error of as small as 0.0223 ± 0.0017 (range 0.0186 to 0.0276 D). Further calculation with equation 3 showed these errors in total corneal power estimation correspond to a mean error in calculation of the keratometric index of 0.000173 ± 0.000008 (range 0.000156 to 0.000194). This is because the corneal thickness (d) is present only in the third term in the right side of the Gaussian optics formula; that is,

$$-\frac{d}{n_c}\times\left(\frac{n_c-1}{r_{ant}}\right)\times\left(\frac{n_a-n_c}{r_{post}}\right)$$

and in that formula, the corneal thickness is in the unit of meters. Thus, although the Pentacam-measured corneal thickness is not viewed as the gold standard, the Pentacam-derived total corneal power must be very close to the actual total corneal power, with an error less than 0.03 D, and the Pentacam-derived keratometric index must be very close to the actual keratometric index in each individual eye, with an error less than 0.0002. On the other hand, as the Pentacam cannot be viewed as the gold standard for corneal thickness measurement, using the Pentacam-derived keratometric index for any other device than the Pentacam would not be justified. The Pentacam-derived keratometric index should be used only for the Pentacam data.

Keratometry has several clinical uses including intraocular lens (IOL) power calculation, contact lens fitting, refractive surgery, and monitoring of corneal changes.[33–36] The most commonly used standardized keratometric index is 1.3375. It was chosen only for convenience, rather than for optical significance, because it makes the 2 values (7.5 mm and 45.0 D) agree exactly.[2,33] For the Gullstrand schematic eye, the keratometric index is 1.3315. Olsen[2] chose this value because it yielded the best results for IOL power calculation. Binkhorst and Holladay chose the value 4/3 as the standardized keratometric index in their IOL power calculation formulas (Binkhorst II formula and Holladay 1 formula).[2,33,37] The SRK/T formula used 1.333 as the standardized keratometric index.[38] The Hoffer Q formula did not designate a specific keratometric index. It used the K value measured by the keratometer in the formula. Therefore, in the Hoffer Q formula, the actual keratometric index used is dependent on which keratometer the clinician uses. (In most cases, a value of 1.3375 is built into the keratometer. In the appendix of Hoffer's paper,[39] the phrase "refractive index of cornea = 1.336" might be a misprint; the correct phrase is "refractive index of aqueous = 1.336".) In our study in which we used the Pentacam to measure the anterior and posterior radii of the BFS and corneal thickness, we determined the mean keratometric index to be 1.3281 with the Gaussian optics formula. This value is lower than the most commonly used value of 1.3375 and the value of 1.3315 derived from the Gullstrand schematic eye (both $P < .0001$, 1-sample t test). Our mean keratometric index is also lower than those used in the third-generation IOL power calculation formulas (1.333 to 1.3375) (all $P < .0001$, 1-sample t test).

As shown in this study, when the keratometric index deviates from the value of 1.3281 (derived physiologically in this study) more significantly, the prediction for the total corneal power will be more inaccurate. In the currently used third-generation theoretical IOL power calculation formulas, the keratometric index used ranged from 1.333 to 1.3375. This range of keratometric index values does not calculate the true corneal power. However, these IOL power calculation formulas have been optimized to account for this priori error in keratometric index (and the total corneal power) by calculating against actual post–cataract surgery refractive outcome (eg, optimizing the A constant and surgeon factor in the Holladay 1 formula, or the ACD constant in the SRK/T formula). With this optimization process, part of the error induced by inaccurate keratometric index is neutralized. If we substitute the original keratometric index used in these formulas with the one developed in our study (1.3281) or other studies (eg, 1.3273,[3] 1.329,[14] and 1.3283[28]) without reoptimizing the formulas and other parameters, significant errors in the IOL power prediction will result. As the measurement of posterior corneal surface becomes more feasible clinically, the true total corneal power can be approximated more closely than before with the newly derived keratometric index (such as the one derived from this study). Future IOL power calculation formulas can be developed based on these newly derived keratometric indices to improve the predictability of IOL power calculation.

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First author:
Jau-Der Ho, MD, PhD

Departments of Ophthalmology, Taipei Medical University Hospital and Taipei Medical University, Taipei, Taiwan