European Journal of Ophthalmology / Vol. 15 no. 1, 2005 / pp. 8-16

Comparison of keratometric and topographic cylinder and axis measurements on normal corneas with low astigmatism

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PURPOSE. *To evaluate agreement in measurements of astigmatic axis power and location between keratometry and computer assisted videokeratography (corneal topography) on normal corneas with less than 1.50 D of idiopathic astigmatism.*
METHODS. *Keratometric readings with the 10 SL/O Zeiss ophthalmometer and corneal topographic maps with the TMS-1 were obtained by two independent examiners on 32 normal corneas. Measurement agreement between the two instruments was evaluated in regard to steep and flat meridian power and location, and in astigmatism magnitude (D).*
RESULTS. *The limits of agreement (d-2 SD to d+2 SD) between the two instruments were found to be broad for clinical purposes in measuring the steep meridian power (-0.16 to -1.20 D), flat meridian power (0.43 to -1.25 D), and astigmatism (0.60 to -1.12 D). A constant bias of the TMS-1 towards the 10 SL/O Zeiss ophthalmometer was found, in measuring steeper both principal meridians and higher amount of astigmatism. Mean location difference was 19° (±19°) for the steep meridian and 17° (±20°) for the flat meridian.*
CONCLUSIONS. *Despite the differences seen in measurements between the 10 SL/O ophthalmometer and the TMS-1, these differences may be clinically small enough for the methods to be used interchangeably in measuring only the magnitude of astigmatism on normal corneas. However, the disagreement in astigmatism axes is too great to be ignored. (Eur J Ophthalmol 2005; 15: 8-16)*

KEY WORDS. *Keratometry, Topography, Videokeratography, Ophthalmometer, Measurement agreement, Astigmatism*

Accepted: September 27, 2004

INTRODUCTION

Computerized videokeratoscopes (CVK) are instruments that calculate the corneal power and reproduce the corneal profile with a certain level of accuracy and precision. Accuracy of a method refers to how close the measured values are to the real value, whereas precision refers to the agreement between repeated observations. A significant amount of research has taken place regarding the accuracy of CVK devices on test surfaces, mainly calibrated test spheres and normal corneas. These results have shown an acceptable level of accuracy and precision for different commercially available models of CVK (1-6). It is equally important, however, and clinically useful, to know the measurement agreement of instruments such as keratometry and CVK (corneal topography), which both measure astigmatism.

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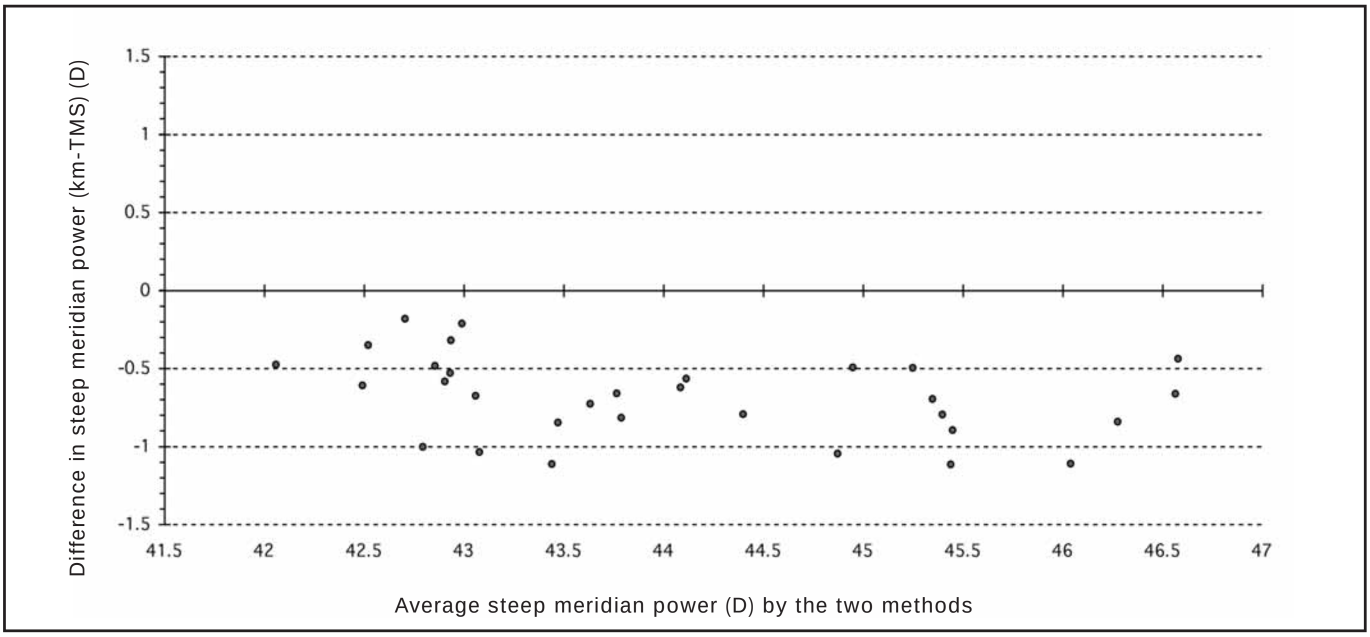

Fig. 1 - *Agreement between keratometry and TMS-1 in measuring steep meridian power on normal corneas.*

The aim of the present study was to compare the measurements between keratometry and videokeratography on normal corneas with low (less than 1.50 D), naturally occurring astigmatism. Evaluation was conducted in terms of dioptric power and axis of the steep and flat corneal meridians, as well as magnitude of corneal astigmatism.

METHODS

Instruments

The keratometer used in this study was the Carl Zeiss 10 SL/O ophthalmometer, applied as an attachment to the Zeiss slit lamp. This is an ophthalmometer following the Helmholtz principle with measured range for radii of curvatures from 4.00 to 11.2 mm. The measured corneal diameter is from 1.5 to 3.5 mm depending on the radius of the examined cornea (7). The scale accuracy throughout the entire measuring range is ±2 x 10^{-2} mm, which is within the recommended tolerance for keratometers (8). This is a two-position instrument and can thus measure principal corneal meridians that are not perpendicular. The CVK used in the study was the TMS-1 (Computed Anatomy, New York, NY, software version 1.61) model with a 25 ring light cone. The range of radius of curvature that can be measured with the instrument is 33.75 to 3.38 mm, corresponding to a 10 to 100 D range of corneal power. This system uses a short working distance of 40 mm. On each videokeratoscope ring the TMS-1 evaluates 256 points (on 256 different meridians). The total analysis includes 6,400 individual power points. The location of these specific points is then calculated in reference to a known calibration file provided by the patented algorithms of the instrument (Datamap). The operator-monitored automated digitization has a resolution of approximately 500 lines per frame, which correlates to a corneal surface resolution of ±0.20 D (9).

Patients

Both corneas from 17 normal subjects (8 male and 9 female) aged 18 to 64 years (mean 36) were studied. The subjects were doctors, nurses, or clerical staff working at Bristol Eye Hospital, or individuals accompanying patients. Corneas were considered normal and included in the study only if there was 1) no history of ocular surgery; 2) no slit-lamp microscopy evidence of trauma or corneal disease; 3) best-corrected visual acuity (BCVA) of 1/10 (0.1) or better to allow adequate fixation; 4) regular keratometric readings; 5) keratometric astigmatism of less than 1.50 D.

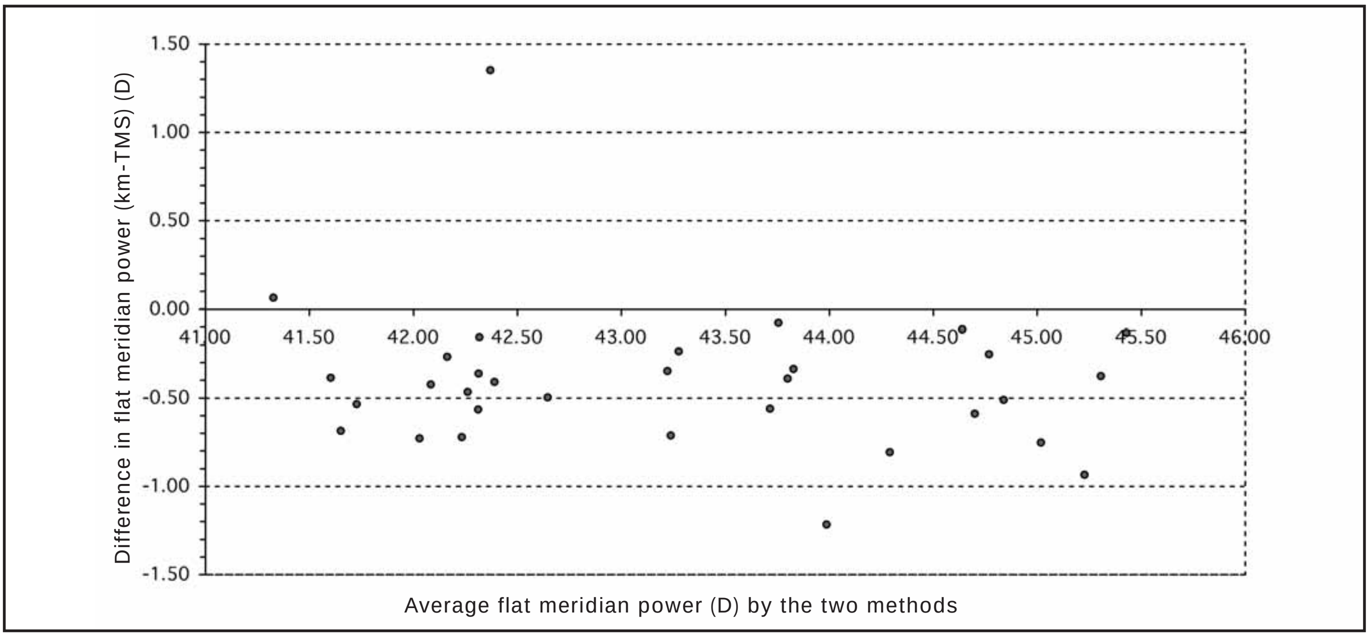

Fig. 2 - *Agreement between keratometry and TMS-1 in measuring flat meridian power on normal corneas.*

Two of the 34 eyes had to be excluded from the study (one due to a central corneal opacity of unknown etiology which produced distorted keratometric mires, and the second because of excess corneal astigmatism). This left 32 normal corneas for analysis.

Examiners and examination conditions

Two independent operators (CHK, IP) took part in the study in a masked fashion. All measurements for a given instrument were made for all patients by both operators, who were well experienced with the use of both the devices. All topographic and keratometric examinations were conducted in the same room, kept in semi-darkness to facilitate fixation. The 10 SL/O Zeiss ophthalmometer had been calibrated before the start of the study and periodically checked using an accurately machined steel ball of known radius of curvature of 7.50 mm as a test surface. The patented solid-state videokeratography system of the TMS-1 had been aligned and calibrated on site by technicians of the manufacture company, with a 45 D calibration sphere.

Measurements

Each observer obtained three measurements from each cornea with both the ophthalmometer and the TMS-1. Patients were instructed to blink and refixate between measurements. No artificial tears were used in any case. The sequence of the measurements with the two instruments was randomized and the two investigators were masked; they had no knowledge of the results obtained by the fellow observer.

Prior to obtaining each measurement by the ophthalmometer, the eyepieces of the instrument were set by each investigator to correct for their refractive error.

All three captured images with the TMS-1 were digitized and processed. Absolute scale topographic maps were obtained for each eye, and the non-orthogonal simulated keratometric (simk) readings (power and axis) for all examinations were obtained from the instrument's display. The simulated keratometric readings of the TMS-1 represent proximate points on the cornea to the location at which a keratometer measures corneal curvature (central 3 mm of the cornea).

Data collection

All data were entered into an integrated spreadsheet program (Microsoft Excel). As the 10 SL/O ophthalmometer model does not provide direct reading of the dioptric power of the cornea at the meridian under examination, the millimeter radius readings were transformed to surface power according to the ker-

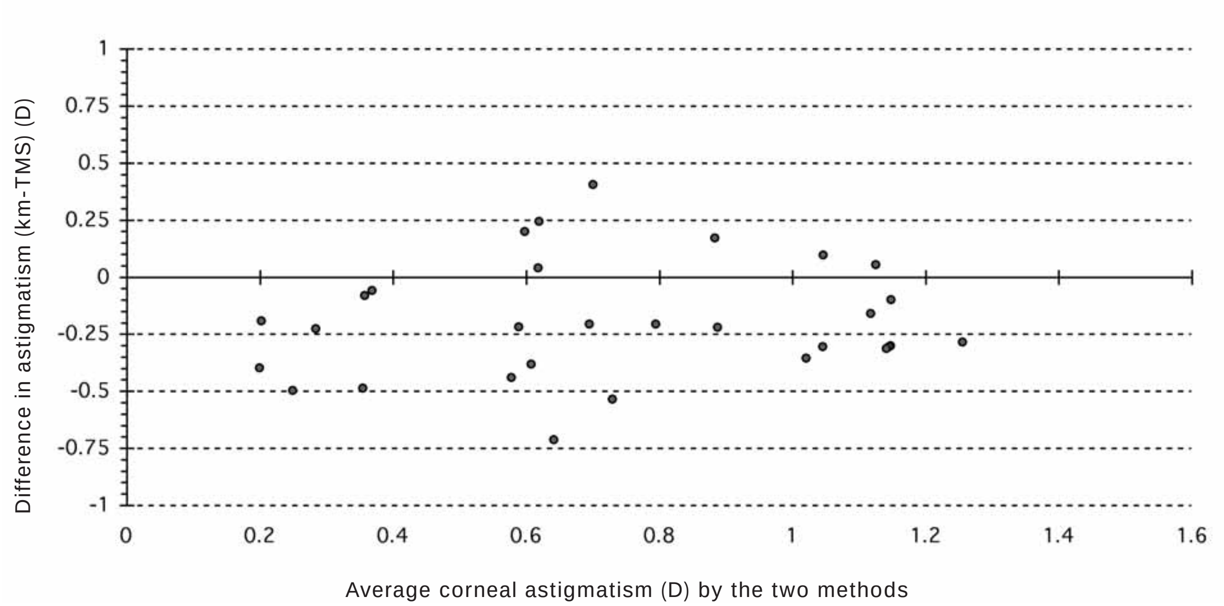

Fig. 3 - *Agreement between keratometry and TMS-1 in measuring amount of corneal astigmatism (D) on normal corneas.*

TABLE I - COMPARISON OF MEASUREMENTS BETWEEN OPHTHALMOMETER AND VIDEOKERATOGRAPHY ON NORMAL CORNEAS (same observer)

Parameter	**No eyes**	**Instrument**	**Power (D) mean ± SD**	**Mean difference (D) (km-TMS)±SD**	**Limits of agreement (D ± 2SD)**	**95% confidence interval for bias***
Power of steep meridian	32	Ophthalmometer TMS-1	43.68 ± 1.29 44.36 ± 1.39	-0.68 (± 0.26)	-0.16 to -1.20 D	-0.58 to -0.78 D
Power of flat meridian	32	Ophthalmometer TMS-1	43.06 ± 1.24 43.48 ± 1.32	-0.41 (± 0.42)	0.43 to -1.25 D	-0.27 to -0.55 D
Astigmatism (D)	32	Ophthalmometer TMS-1	0.62 ± 0.36 0.88 ± 0.44	-0.26 (± 0.43)	0.60 to -1.12 D	-0.12 to -0.40 D
Location comparison				**Mean difference (º) (km-TMS] ± SD**		
Steep meridian angle (º)	30	Ophthalmometer TMS-1		19º (± 19º) §	-19º to 57º	12º to 26º
Flat meridian angle (º)	30	Ophthalmometer TMS-1		17º (± 20º) §	-22º to 54º	10º to 24º

* Bias is the mean difference (km-TMS), and 95% confidence limits calculated as d ± (t x SE), with t0.05, n-1 degrees of freedom
§ All values transformed to (+) difference in degrees

atometric formula D = n-1/R. A refractive index of 1.3375 was assumed for conversion from sphere radius to diopters. The notation of 0° and 180° meridians for cylinder axis presents a potential problem for analysis. Because the maximum possible difference in cylinder axis is 90°, 180° was added to or subtracted from the difference in cylinder axis if that was greater than 90°.

Statistical analysis

Differences in measurements between the two instruments (y–x) were calculated and plotted against the mean of the two instruments' measurements, according to the methods described by Bland and Altman (10). The mean of the differences (d) represents the bias between the two instruments. The limits of agreement were calculated as d 2±SD*, and the 95% confidence intervals for the bias (mean difference) calculated by d±(t x SE), t 0.05, n-1** degrees of freedom. Confidence intervals are intervals that with high probability contain the true difference. The difference in outcomes was considered significant at the 5% level, if the 95% confidence interval did not contain the value of zero (11). Additionally, the percentages of scores within specific ranges were determined.

For the calculation of measuring agreement between the two instruments, the mean of the three measurements with each method, performed by the same examiner, was selected.

RESULTS

Power measurements

Statistical data of the results of power measurements for both instruments on normal corneas are presented in Table I. Statistically significant differences (95% confidence limits not including 0) between the two instruments were found in measuring the dioptric power (D) of the steep and flat meridians, as well as amount of astigmatism. A systematic (constant and reproducible) bias was revealed in the measurements of all these parameters. There was a tendency for the TMS-1 to measure higher values than the 10 SL/0 ophthalmometer for the steep meridian power in all 32 measurements (mean –0.68 D, SD 0.26 D). This strong bias is shown in Figure 1, and by the limits of agreement values and confidence intervals (Tab. I). For the measurements of the flat meridian, the TMS-1 also demonstrated a bias toward recording higher power values than the keratometer in 30 out of the 32 (94%) measurements (Fig. 2). The absolute mean difference was –0.41 D (SD 0.42). If 0.50 D is considered a clinically acceptable difference between the instruments, Table II shows that in only 31% of the measurements of steep axis power the agreement was better than 0.50 D; this percentage for the flat meridian measurements is 56%. For a clinical agreement of 0.25 D, these percentages fall to 6.25% and 18.75%, respectively. For the astigmatism magnitude, the bias again was for the TMS-1, which in 23/32 cases (72%) recorded higher astigmatism than did the keratometer (Fig. 3, Tab. I).

Location measurements

In two eyes, the keratometric astigmatism was equal to zero, and these eyes were excluded from the comparison. The measurement agreement between the two

TABLE II - DISTRIBUTION OF DIFFERENCE IN POWER READINGS BETWEEN THE 10 SL/O OPHTHALMOMETER AND TMS-1

Difference between instruments (D)	Steep meridian	Flat meridian
0 – 0.25	2 (6.25%)	6 (18.75%)
0.25 – 0.50	8 (25%)	12 (37.5%)
0.50 – 1.00	16 (50%)	12 (37.5%)
1.0 – 1.50	6 (18.75%)	2 (6.25%)
1.50 – 3.00	–	–
> 3.00	–	–
Total	32 eyes	32 eyes

* d= Mean difference
SD = Standard Deviation
** SE= Standard error of the mean n 1 degrees of freedom

instruments was 19° (mean value, with 19° SD) for the steep meridian angle, and 17° (20° SD) for the flat meridian location (Tab. I). However, the measured differences in axes between the two instruments compared to the measured astigmatism (Tab. III) in 19 of the 60 measurements were more than 20°. There was a tendency for more than 30° disagreement between the two instruments in smaller degrees of astigmatism, whereas higher values of astigmatism tended to give measurement agreement better than 20°.

DISCUSSION

Previous studies (1-6, 12, 13) have assessed the accuracy and precision of the instruments on measuring artificial surfaces, but an instrument capable of accurate readings on test spheres cannot be considered a priori equally accurate on aspherical surfaces such as the human cornea. Furthermore, in the case of human corneas, it is only the reproducibility (also called precision), repeatability, or comparison of measurements that can be assessed rather than the accuracy, as the absolute power of a human cornea is unknown.

Hannush et al (1), comparing the keratometer to the CMS topography on steel spheres, concluded that both show an accuracy within the clinically acceptable range (±0.27 D). However, the CMS was less accurate for surfaces steeper than the normal corneas (50 D test ball). Comparison studies of accuracy between different models of videokeratography on calibrated spheres have also been performed by other investigators, with inconsistent results (3, 4, 6, 12, 13). The accuracy and precision performance depends on the shape of the measured surface, with decreasing accuracy on rapidly flattening surfaces for both central and peripheral radii of curvature (12).

Although there are later models of CVK, the TMS-1 remains one of the most popular ones and the one we had access to at the time of the study. In the present study, the degree of agreement between keratometry

TABLE III - DISTRIBUTION OF DIFFERENCES IN AXIS LOCATION OBTAINED WITH THE 10 SL/O OPHTHALMOMETER AND THE TMS-1, COMPARED TO MEASURED ASTIGMATISM, ON NORMAL CORNEAS

	Difference in axis measurement (degrees) between ophthalmometer and TMS-1				
Mean measured astigmatism (D)*	**0 – 10º**	**10 – 20º**	**20 – 30º**	**> 30º**	
0 – 0.25				1 (3.3%)	Steep meridian
				1 (3.3%)	Flat meridian
0.25 – 0.50	1 (3.3%)	1 (3.3%)	1 (3.3%)	1 (3.3%)	Steep meridian
					Flat meridian
0.50 – 0.75	3 (10%)	3 (10%)	3 (10%)	2 (6.6%)	Steep meridian
	3 (10%)	2 (6.6%)		2 (6.6%)	Flat meridian
0.75 – 1.00	–	2 (6.6%)	–	1 (3.3%)	Steep meridian
	2 (6.6%)	1 (3.3%)	–	–	Flat meridian
1.00 – 1.25	6 (20%)	2 (6.6%)	1 (3.3%)		Steep meridian
	7 (23.3%)	2 (6.6%)			Flat meridian
1.25 – 1.50	1 (3.3%)	1 (3.3%)			Steep meridian
	1 (3.3%)	1 (3.3%)			Flat meridian

*Average by both instruments' measurements (results on 30 paired measurements) and videokeratography was assessed with a previously described analysis technique for method comparison data (10). The use of a correlation coefficient that has been used in other investigations has been avoided here. A high correlation does not necessarily mean that the two methods agree, as data that seem to be in poor agreement can produce quite high correlations (10, 14, 15).

In our study, statistically significant differences were found between the keratometer (Zeiss ophthalmometer, model 10 SL/0) and videokeratography (TMS-1 model) in measuring both steep and flat meridians as well as amount of corneal astigmatism. There was a constant and reproducible bias of the TMS-1 to measure steeper than the ophthalmometer, for both principal meridians. This finding is in agreement with Hannush et al (1) who found that the keratometer (Bausch & Lomb) generally read lower values, and the CMS higher values than calibrated steel spheres. Although the authors reported the differences not to be statistically significant, they came to that conclusion by only comparing the mean deviation scores. In another study on 20 normal corneas (16), the mean absolute difference between the keratometer (Marco model-1) and the EyeSys device was found to be 0.19 D for the steep meridian power and 0.21 D for the flat meridian. In that study as well, higher mean values were given by the EyeSys than by the keratometer for both steep and flat meridian power. In our study, the differences between the two instruments were higher (0.68 D ± 0.26 for the steep meridian, and 0.41 D ± 0.42 D for the flat meridian). Davies and Dresner (17) performed their own comparison study between the keratometer (Marco model-1) and the EH-270 corneal topography. For readings obtained from 14 normal corneas, excellent correlation was achieved between keratometry and the EH-270 (0.969 for the vertical meridian and 0.972 for the horizontal meridian measurements). In another study (18) a statistically significantly steeper average value (0.13±0.47 D) was observed with the EyeSys unit compared to keratometry for the flat meridian, but no significant difference was found for the steep meridian power. Zadnik et al (19) have found results very similar to ours, by comparing keratometry (Bausch & Lomb) to TMS-1 on 29 normal eyes, and by using the same statistical procedures as here. TMS-1 videokeratography yielded significantly steeper corneal curvature values when compared to keratometry, in both the horizontal (mean -0.47 D, SD 0.47 D) and the vertical meridians (mean -0.22, SD 0.57 D). In addition, the Topcon autokeratometer and the EyeSys topography have shown reasonable agreement for surface topography on convex conicoidal plastic test surfaces, but not for normal human corneas (20).

There is therefore quite strong evidence from a number of studies indicating an inherent tendency of the CVK devices to measure steeper than the keratometer. This is not a fact related to a specific model, but rather shared by instruments of different manufactures. This was also a consistent finding of our study, but the differences seen with others' results may be attributed to one of several factors including the use of different instruments, different test surfaces (calibrated spheres, normal corneas), or different statistical methods between the various studies. In our previous report on postkeratoplasty human corneas, we reported similar differences in measurements between the same instruments of our study (21). Also, in a study performed on eyes after penetrating keratoplasty, Borderie et al (22) found that there was a stronger correlation between topographic cylinder magnitude and keratometric axis to the manifest refraction, rather than between the two instruments. Finally, in a study performed in eyes undergoing myopic photorefractive keratectomy (PRK) (23), topographic analysis was found to overestimate astigmatic values systematically before and after PRK.

Another finding of our study is that despite a tendency of the TMS-1 to record higher values than the ophthalmometer, the measurements on astigmatism magnitude between the two instruments approached clinically acceptable agreement. Wilson et al (3) checked on the agreement between keratometry (Bausch & Lomb), TMS-1, and EyeSys on 22 normal corneas. It was found that in measuring corneal astigmatism, EyeSys underestimates the keratometer cylinder by about 23%; the difference between keratometry and TMS-1, however, was not significant. Regarding cylinder axis location, the mean difference found between TMS-1 and keratometer was 21.3 ± 28.1°, while the TMS-1 had more difficulty in identifying the major corneal axis in corneas with lower cylinders. The latter results are in agreement with the findings of the present study (19°±19° for the steep meridian, 17°±20° for the flat, better axis location agreement in higher cylinders, Tab. III). However, we cannot conclude that the source of axis bias is the TMS-1. It could well arise from differences in head rotation during measurements with the two instruments. The results are not surprising as with any given instrument measuring curvature differences between axes, it is more difficult to identify small differences in axis location in eyes with low degrees of astigmatism rather than in eyes with higher astigmatism. It is shown in Table III that larger cylinders tend to have higher agreement in axis.

The performance of the videokeratography device used here (TMS-1) was probably below the expectations arising from previous studies on test spherical surfaces (1-3, 5), but this emphasizes the difference between experiments on spheres and *in vivo* tests. On the other hand, the same model has been shown to give readings for the vertex radius that were higher than those of the calibrated ellipsoidal convex surfaces, up to 0.09 mm greater (24), as the surface becomes increasingly aspheric. Although keratometry and CVK share some common assumptions, they also differ in other respects (25). There are some sources of inaccuracy in CVK that may arise from the instrument itself, or from the algorithms used. Short working distance CVK such as the TMS-1 are more sensitive to defocusing errors (26). With the keratometer, due to the greater distance between instrument and target, focusing is less critical. There are also fundamental limitations of the keratoscopic design, as errors can be introduced due to poor focus of different rings if these are not on the same plane (5, 27). Potential inaccuracies in CVK arise also from the algorithms used. There is no known mathematical formula that describes exactly the shape of the normal cornea; therefore the algorithm, whatever it is, gives an approximation of the corneal shape. The algorithms employed by the TMS-1 used in our study assume that the cornea is spherical, but algorithms that work well for spheres may not work adequately for an aspheric surface such as the human cornea (6). The keratometer measurements are also correct only when the surface examined is spherical or toroidal with the mires in the meridian planes of greatest or least curvature. An assumption is made that the surface between the two measuring points is spherical. Depending on the shape deviation from that of a sphere, errors can be induced in the measurements of a surface. However, the clinical results of this study suggest that the introduced error in aspheric surfaces is smaller than in the TMS-1 and result in a better reproducibility with the keratometer. We have previously shown that the SL/O ophthalmometer is more reproducible than the TMS-1 both for normal and postkeratoplasty corneas (7). A systematic error in the CVK computer algorithms was suggested by the results of a study with calibrated steel balls where a clustering of deviation score values was noted on the positive side of zero for calibrated balls of 38 D, 43 D, and 50 D (1). Such a systematic error in algorithms could account for the observed bias in the present study. Furthermore, although both instruments measure similar cord lengths, they may not measure exactly the same cord length. Roberts (28) concluded that the misalignment error is small compared to the inherent error due to a spherically biased reconstruction algorithm.

In summary, the present study indicates that a constant and reproducible bias of the TMS-1 towards the 10 SL/O Zeiss ophthalmometer exists, in measuring steeper both principal meridians and higher amount of astigmatism in normal corneas. Significant differences were also observed in meridian axes. The relative contribution of the possible factors to the observed findings was not part of the study design; however, possible explanations are discussed. Further comparative studies between the two instruments are needed, specifically targeted at identifying the responsible factors for the observed differences.

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