Standard vs. Automated Keratometry

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Introduction

The following is a study investigating the ability of two different keratometers to predict astigmatic refractive error. The keratometers being investigated are the Bausch and Lomb Keratometer and the Humphrey model 410 Autokeratometer. These instruments utilize very different mechanisms in measuring the curvature of the cornea. Because of the differing mechanisms, it may be possible that the corneal astigmatism measured by each instrument may correlate differently with the subjective astigmatic refractive error of a given eye. The purpose of this study is to determine if either one of these instruments is a better predictor of astigmatic refractive error. Before detailing the experimental method, apropriate background information will be discussed.

The Humphrey model 410 Autokeratometer is a recently developed instrument utilized to measure corneal topography. It renders much more information than does a manual keratometer. This additional information can be usefull in fitting contact lenses, and in diagnosing corneal problems.

The Autokeratometer measures the cornea in a manner very different from that of a standard keatometer. The Autokeratometer measures the cornea in three different places. A central measurement is made about the visual axis. Two periphreal measurements are made 13.5 nasal and temporal to the visual axis. Each of the measurements are determined from a three spot pattern formed on the cornea by light from infrared emiting diodes. The spots are arranged in a circular pattern with an average diameter of 2.6 mm. The light reflected off of the cornea is deflected into solid state detectors for analysis.

The information yielded from these three measurements is fed into a microprocessor for further analysis. This microprocessor calculates apical keratometry values, apex position, and the corneal shape factor(degree of flattening or steepening of the cornea towards it's periphery). It also calculates a tolerance value for apex position, and a conformance factor, which indicates the cornea's deviation from an "ideal" shape. This additional information, as previously mentioned, is usefull in contact lens fitting and corneal diagnosis. This information, however, is not the focus of this investigation.

The measurement to be analyzed in this study is the Autokeratometer's central keratometric measurement. This measurement is paralled with the measurement of a standard keratometer. It is, once again, determined by automated analysis of the three spots of infrared light reflected off of the cornea about the visual axis. This contrasts with the measuring system of the Bausch and Lomb Keratometer, which is based on measuring the size of the reflection of a circular mire of light off of the anterior corneal surface. The size of the mire is measured indirectly by utilizing a doubling prism mechanism based on methods developed by Sutcliff. Diagrams of the optical systems of the two keratometers are included in the appendix.

Previous studies have compared the Humphrey Autokeratometer to manual keratometers based on different criterion than that in this study. In an investigation by Koetting, et. al., a comparison was made as to the overall steepness of corneal measurments of the Humphrey Autokeratometer and of the Topcon OM 3 Keratometer. This study found that the Autokeratometer measured an aveage of 0.03 mm steeper than the OM 3. The authors felt that this difference was likley due to the greater fixation control of the Autokeratometer, keeping it's measurment better centered on the cornea.

In another study by Halberg, et. al., the Autokeratometer was compared to a conventional keratometer utilizing several different criterion. The first criterion tested was that of each keratometer's accuracy in measuring a known standard calibration sphere. Both instruments were shown to be acurate within clinical ranges. The Autokeratometer demonstrated an accuracy of within 0.12 DK, while the manual keratometer showed calibration shifts of 0.25 to 0.58 DK.

A second aspect of the study compared the repeatability of the two instruments. This was assesed by comparing three measurements made with each keratometer on each of a sample of corneas. Results showed that both keratometers were equally repeatable for power measurements. The repeatability of the axis measurement of the manual keratometer was shown to be dependent upon the experiance of the operator.

The third section of this study was a direct comparison of the central corneal measurements obtianed with each instrument. This data revealed an average difference of 0.25 DK in power, and 7.8° in axis.

The purpose of the study, which is the subject of this report, is to asses and compare the ability of the Humphrey Autokeratometer and the Bausch and Lomb Keratometer to predict astigmatic refractive error. The experimental design of this study follows.

Population

The population for this study is composed of students and patients of the Ferris State College of Optometry. Each subject of the population has at least 0.50 D of

astigmatic refractive error in each eye. Furthermore, the subject's eyes are free of any condition which could significantly alter the predictability of, or accuracy in determining the refractive error. Conditions which would cause rejection of a subject for this study include:
1) Corneal conditions; visually significant opacities, surgical scarring, keratoconus or other serious dystrophy, irregular astigmatism, corneal edema.
2) Lenticular conditions; aphakia, visually significant nuclear sclerosis or other significant cataracts.
3) Conditions reducing corrected visual acuity; vitreal, retinal, or neurological conditions, amblyopia.

A total of 23 eyes (12 subjects) were included in this study. Astigmatic refractive errors ranged from 0.50 to 4.50 D. Fourteen eyes demonstrated with the rule astigmatism (minus cylider axis within 20° of 180°). Six eyes showed against the rule astigmatism (minus cylinder axis within 20° of 090°). Three eyes had oblique astigmatism (minus cylider axis outside of above stated ranges).

Procedure

Each subject in this study underwent two keratometric measurements on each eye. One was obtained using the Humphrey model 410 Autokeratometer. The other was obtained with the Bausch and Lomb Keratometer. Each subject also recieved a carefully executed subjective refraction. This refraction was performed by utilizing static retinoscopy as a starting point, and refined using the Jackson cross cylinder. All three procedures were performed by the author of this study.

Data

Three pieces of raw data were generated for each eye considered; 1) The power and axis measurements of the

Bausch and Lomb Keratometer. 2) The power and axis measurements of the central keratometric measurement of the Autokeratometer. 3) The spherocylindrical refractive error finding.

Each piece of data was manipulated for comparative purposes. The refractive findings were reduced to the cylindrical portion only, yielding a negative power difference between meridians, and the axis of it's orientation (i.e., -0.75 X 168). The two keratometric findings were transcribed to this form as well, yielding a negative power difference and axis. The keratometric findings were then modified by a mathematical formula known as Javal's rule, and the result rounded to the nearest 0.125 D. This formula compensates for the normal major discrepencies between corneal and refractive astigmatism. Further discussion about Javal's rule, the afore mentioned discrepency, and the author's choise of compensation for it will apear later in this report.

Results

With the raw data thus modified, direct comparisons are made between the astigmatic refractive error predicted by each keratometer, and the subjective astigmatic refractive error. Comparisons are made in referance to differences in power and in axis seperatley. Additional comparisons are made considering certain segments of the subject population.

The following is a key to the symbols utilized in refering to the comparisons made:

$|\Delta P|$ - The absolute dioptric power difference between the amount of astigmatism predicted by each keratometer, and the amount of the subjective astigmatic refractive error.

ΔP- The dioptric power difference between the amount of astigmatism predicted by each keratometer, and the amount of the subjective astigmatic refractive error, taking into account the direction of the difference (toward WTR or toward ATR).

→WTR- Keratometricaly predicted astigmatism, which is an overestimation of WTR astigmatism, or an underestimation of ATR astigmatism.

→ATR- Keratometricaly predicted astigmatism, which is an overestimation of ATR astigmatism, or an underestimation of WTR astigmatism.

Δ A- The amount in degrees by which the keratometricaly predicted axis differs from the axis of the astigmatic refractive error.

n- The number of eyes included in a comparitive analysis.

$\bar{X}$- The mean difference between keratometricaly predicted data and refractive data. $\bar{X}=\frac{\sum x_1-x_2}{n}$

SD- The standard deviation (measure of variance) of given data. $SD=\sqrt{\frac{\Sigma(x_1-x_2)^2}{n}}$

mode- The most commonly occuring difference between keratometricaly predicted data and refractive data.

range- The actual amount of the least and greatest differences between keratometricaly predicted data and refractive data.

Comparative Results for all Subjects

	B & L Keratometer	Humphrey Autokeratometer
$\lvert\Delta P\rvert$		
$\bar{X}$	0.522 D	0.408 D
SD	0.690	0.507
mode	0.50 D (6)	0.25 D (8)
range	0.00 to 1.50 D	0.00 to 1.25 D
n	23	23
ΔP		
$\bar{X}$	0.162 D→WTR	0.319 D→WTR
SD	0.731	0.527
mode	0.50 D→WTR (6)	0.75 D→WTR (5)
range	1.25 D→ATR to 1.50→WTR	0.50 D→ATR to 1.25 D→WTR
n	20	20

Comparative Results for all Subjects con't.

	B & L Keratometer	Humphrey Autokeratometer
ΔA		
$\bar{X}$	6.87°	7.56°
SD	9.58	10.71
mode	5° (6)	2° (4)
range	0° to 25°	0° to 29°
n	23	23

Comparative Results for Cases of WTR Astigmatism

$\lvert\Delta P\rvert$		
$\bar{X}$	0.438 D	0.375 D
SD	0.516	0.465
mode	0.50 D (5)	0.75 D (4)
range	0.125 to 1.125 D	0.00 to 0.75 D
n	14	14
ΔP		
$\bar{X}$	0.223 D→WTR	0.268 D→WTR
SD	0.516	0.465
mode	0.50 D→WTR (5)	0.75 D→WTR (4)
range	1.125→ATR to 0.875 D→WTR	0.50→ATR to 0.75 D→WTR
n	14	14
ΔA		
$\bar{X}$	4.57°	3.79°
SD	5.58	5.16
mode	3° (4)	2° (4)
range	1° to 10°	0° to 10°
n	14	14

Comparative Results for Cases of ATR astigmatism

	B & L Keratometer	Humphrey Autokeratometer
$\lvert \Delta P \rvert$		
$\bar{X}$	0.896 D	0.521 D
SD	0.863	0.648
mode	1.25 D (3)	0.25 D (2)
range	0.00 to 1.50 D	0.125 to 1.25 D
n	6	6
ΔP		
$\bar{X}$	0.021 D→WTR	0.271 D→WTR
SD	0.863	0.648
mode	1.25 D→ATR	none
range	1.25→ATR to 1.50 D→WTR	0.50→ATR to 1.25 D→WTR
n	6	6
ΔA		
$\bar{X}$	14.5°	12.8°
SD	16.6	15.4
mode	5° (2)	7° (2)
range	5° to 25°	7° to 29°
n	6	6

Before drawing conclusions from the reported results, some considerations about the experimental methods used in this study will be discussed. The first consideration is the relationship between corneal astigmatism as measured with a keratometer, and the subjective astigmatic refractive error. Borish presents a summary of the major factors contributing to the discrepency between these two measurements: 1) The physiologic lenticular astigmatism. 2) The curvature of the posterior corneal surface. 3) The vertex difference between the corneal plane and the spectacle plane. 4) The variation in index of the cornea from that assumed by the keratometer. 5) The refractive effect of the aqueous. 6) The aberational effect of the pupil exposing a larger area of the cornea than that measured by the keratometer. 7) The obliquity of the of the line of sight from the true anterior pole of the cornea when measured.

A number of attempts have been made at developing rules and formulas to compensate for these factors. Rules have been developed by Javal, Sutcliff, O'Shea, McCulloch, Kratz and Walton, and tabular systems by Neumueller and Tait. The author has chosen to utilize Javal's rule, which attempts to compensate for the vertex change, and the normal physiologic lenticular astigmatism, which are usually the most clinically significant factors involved. Javal's rule is expressed as:

$$Ast_t = K + P\ (Ast_c)$$

Where:
Ast_t = The predicted astigmatic refractive error.
Ast_c = The measured corneal astigmatism.
K = -0.50 D X 090 = The normal physiologic lenticular astig.
P = 1.25 = The correction factor for vertex change.

An illustration of applying Javal's rule:
If keratometry reveals: 44.00@180; 45.00@090
This gives: Ast_c = -1.00 X 180
Ast_t = (-1.00 X 180) 1.25 + -0.50 X 090
Ast_t = -1.25 X 180 + -0.50 X 090
Ast_t = -0.75 D X 180

If the axes of the corneal astigmatism are slightly off from 180 and 090, the -0.50 D X 090 is added to the meridian closest to 090. In cases of oblique astigmatism, this factor is left out of the calculation. In this study, the value given by Javal's rule was then rounded to the nearest 0.125 D for comparative purposes.

The use of Javal's rule to predict astigmatic refractive error is obviosly not an exact method, but rather, it is a clinically usefull estimation. The actual effect of the previously mentioned factors on astigmatic refractive error could vary significantly from one eye to the next. Reasearch by Mote and Fry showed that Javal's rule is a fairly accurate predictor, but that discrepecies of up to 1.50 D are possible.

There are other factors which could alter the significance of the data generated in this study. An important consideration is the small number of subjects which made up the population. Data was generated for many more subjects than were included, but several were excluded primarily because the amount of astigmatism was too low (less than 0.50 D) to be considered.

Possible errors in the data itself should also be considered. The astigmatic refractive error determined for each subject could vary in some degree in power and/or axis, depending upon the subject's resonses, and the examiner's interpretation of these responses. Furthermore, the consistancy of the subject's fixation could affect the findings of both keratometers. The measurement found with the manual keratometer could also vary due to the examiner's intepretation of mire alignment. Although these potential shortcomings in the experimental methods exist, the following conclusions are drawn.

Conclusions

A) General trends common to both instruments:

1) The average absolute difference between the astigmatic refractive error and the keratometricaly predicted astigmatism is aproximately 0.50 D for both keratometers.

2) The above stated difference is generally a prediction slanted toward with the rule astigmatism for both instuments when considering all cases, and when considering WTR and ATR cases seperately.

3) The average difference between the refractive cylider axis , and the predicted cylinder axis is aproximately 7°.

4) Both instruments show an increased accuracy in predicting the power and the axis in cases of WTR astigmatism as opposed to cases of ATR astigmatism. This may be due in part to the greater number of cases of WTR astigmatism considered.

B) General trends which demonstrate a significant difference between the instruments:

1) The Autokeratometer consistantly shows a greater tendency to predict the astigmatism errantly toward with the rule astigmatism than does the Bausch and Lomb Keratometer.

2) In all comparative trials except one, the mean difference results for the Autokeratometer demonstrate a smaller standard deviation value than the results for the Bausch and Lomb Keratometer. This implies that the results of the Autokeratometer are more homogeneous, or consistant in thier comparison to the refractive data.

In summary, this study has shown that both keratometers are virtually equal in thier ability to predict astigmatic refractive error for both power and axis. However, the comparative findings for the Autokeratometer demonstrate a greater consistancy in the amount and direction of errant prediction than do the comparative findings for the Bausch and Lomb Keratometer.

APPENDIX

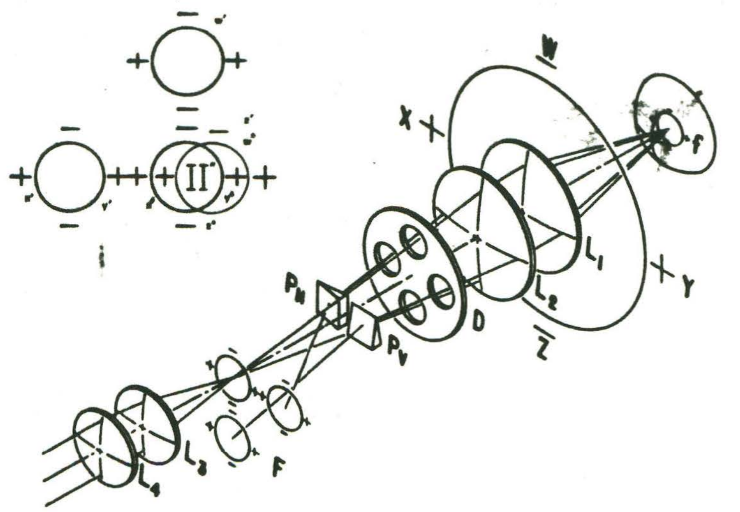
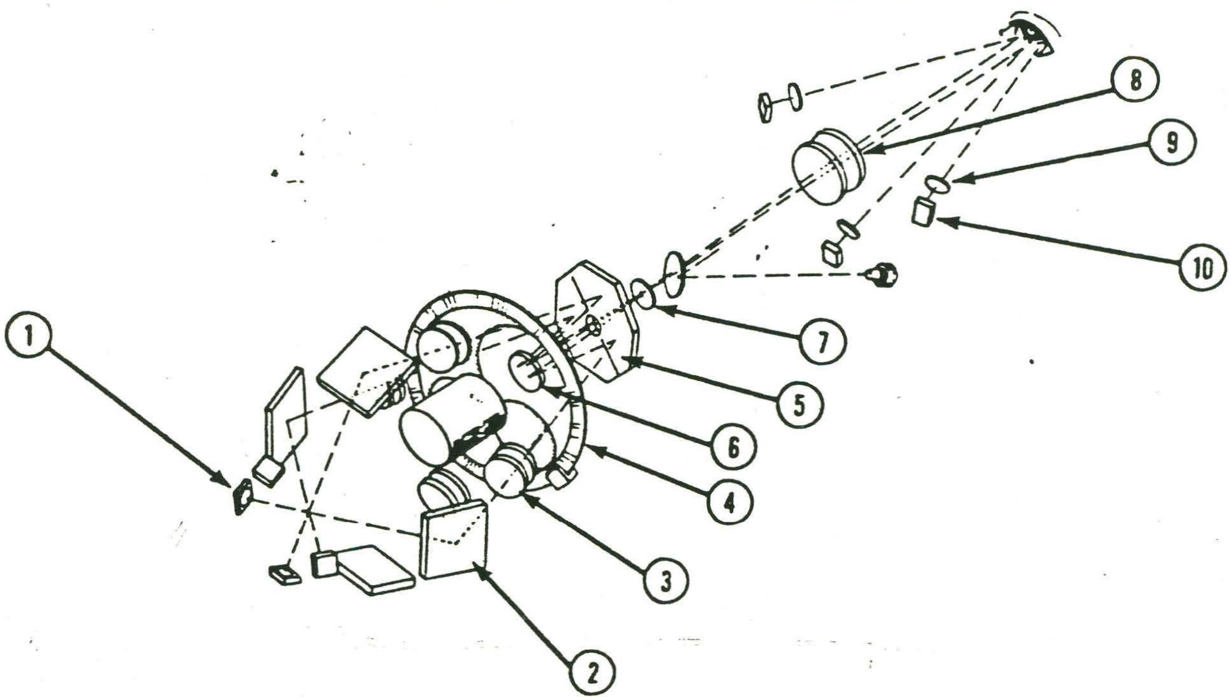


Figure XVI-7 – Diagrammatic simplified representation of keratometer system. f focal plane of cornea; F focal plane of objective of eyepiece (L_3); L_1 and L_2 condensing system; L_3 and L_4 eyepiece; D separating diaphragm; Pv vertical prism; Ph horizontal prism; X to Y mires indicating diameter of horizontal object; W to Z mires indicating diameter of vertical object; x' to x'' horizontal image (diameter) also y' to y''; w' to w'' vertical image (diameter) also z' to z''; I and I'' focal images represented with instrument out of focus. Images are too large for separation of mires X and Y and W and Z, and mires y' and x'' and



AUTO KERATOMETER OPTICAL SYSTEM

Fig. 1 Auto Keratometer Optical Pathway

The measurement begins when 3 beams of light are generated by infrared sources. (1) These beams are folded by reflection from an IR-mirror (2), and passed through condensing lenses (3) onto a rotating chopping disc. The illuminated field, modulated by the disc, is then folded by reflection from a quad mirror (5) and a convex secondary mirror (6), passed through an aperture (7), and finally through a measuring lens (8) at the face of the optics. The beams reflected from the cornea are detected by a photo detector (10) looking through a detector lens (9).

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