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Visual acuity as a function of hydrophilic lens topography

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VISUAL ACUITY
AS A FUNCTION OF
HYDROPHILIC LENS TOPOGRAPHY

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INTRODUCTION

A common complaint among hydrophilic contact lens wearers is that visual acuity is inferior to that obtained with hard lenses or spectacle lenses.[1] Another common complaint is that visual acuity with soft lenses is variable. The use of Snellen notation as a description of vision is found to be inadequate since many patients report poor vision even when good visual acuity is achieved.[2]

As new hydrophilic contact lenses gain FDA approval, it is reasonable to assume that more patients will be fitted with soft lenses, and thus, increase the possibility that practitioners will be faced with the dilemma of not attaining 20/20 visual acuity with this type of lens. We propose to develope a means of assessing the manner by which hydrophilic contact lenses conform to varying amounts of corneal asphericity.

LITERATURE REVIEW

Visual acuity with hydrophilic lenses is usually one Snellen line less than that achieved with spectacle lenses.[2,3] Visual acuity with regular hard corneal contact lenses is found not to differ significantly from that achieved with spectacles. Visual acuity is found to be variable with hydrophilic contact lenses. Snellen acuity fails to provide an accurate description of the vision produced by hydrophilic lenses since many patients complain of poor vision even when 20/20 acuity was achieved. The most common cause of rejection of the hydrophilic lens is unacceptable vision eventhough 20/30 or better acuity had been achieved.[2]

All hydrophilic contact lenses should be verified before dispensing; otherwise, faulty lens parameters could contribute to an unsuccessful fit. The power of the B & L Soflens has been shown to vary from that indicated on the vial.[4] The lenses tend to be significantly greater in minus power as shown by measurement with the lensometer and the power effect of the lens when on the human eye.[4]

Studies have shown that most of the corneal toricity is linearly transferred to the front surface of the hydrophilic lens. Since the hydrophilic lens doesn't eliminate corneal cylinder, approximately 84% of the refractive cylinder will be manifest as the residual astigmatism. Astigmatism alone may not be the limiting factor since Sarver has shown that it is possible to have good visual acuity with a large residual astigmatism.[2] It is also possible to have poor visual acuity while no residual astigmatism is manifest.[2] Hydrogel lens manufacturers recommend use of thicker lenses to reduce the residual astigmatism. However, corneal toricity is transferred directly through the lens regardless of the thickness.[5] The hydrophilic lens actually behaves as though it were an extension of the cornea, since it conforms so closely.[2,5,8] Feldman reports that residual astigmatism became an important limiting factor to visual acuity only when coupled with a large difference between the eccentricity values of the two major meridians. Also, he was unable to establish a relationship between refraction and keratometry that would explain poor acuity.[6]

Changes in spherical aberration have also been postulated as a contributor to the reduced visual acuity.[12] Calculations have been performed and measurements made which show that there is no significant difference in the amount of spherical aberration when hard and soft contact lenses are worn.[7] Other contributing factors may be flexure of gel lens due to lid tension or inferior limbal bearing due to effects of gravity, lens movement or lag, lens rotation, poor cornea-lens bearing relationship, improper diameter,[5] improper blink and dehydration.

When a gel contact lens is placed on the eye, it tends to conform to the corneal contour; and it is usually assumed that no fluid lens exists. It is recognized, however, that the conformation of the lens is not always complete; and that sometimes a significant fluid lens will be present.[4]

According to Sarver, a given lens will undergo steepening or flattening flexure up to some limit imposed by the physical properties of the lens and characteristics of the cornea. If this limit is surpassed, then the lens will support a fluid lens which may be of sufficient magnitude to negate any positive flexure of that lens.[9]

From his work with PEK, Feldman has shown that corneal eccentricity can influence the tear layer thickness.[6] His data demonstrates that the greater the eccentricity, the more flattening occurs paracentrally; and this in turn causes a greater apical clearance. This explains the peculiar occurance of "steep symptoms" with lenses fitted "on K". With lower eccentricities, an "on K" fit can exhibit excessively "flat symptoms".

The range of normal eccentricities in the population is 0.200-0.800 peeking at 0.500.[10] The normal range of shape factors for the same population is -0.15-+0.60.[10] Patients with eccentricities outside of the normal range are likely to be unsuccessful in their attempts to wear hydrophilic lenses. This is especially true when the eccentricity is normal in one meridian and atypical in another.[6]

Feldman arrived at an empiricle screening criterion to evaluate all patients prior to the fitting of B & L Soflens. The criteria for a successful fit are:

1. Eccentricity values should be within the range of 0.200-0.700.

2. The keratometric and refractive cylinders should agree within 0.50 diopters.

3. The arithmetic difference between the eccentricities of the major meridians should not exceed 0.300.

On the basis of the above criteria, Feldman screened 193 patients, of which 122 were selected for fitting. 113 (92.6%) of these became successful wearers of the B & L Soflens.[6]

The PEK, though useful in screening potential B & L Soflens wearers, cannot be used to obtain a readout of parameters for an initial lens. While the computer can describe the amount of corneal peripheral flattening, it cannot suggest parameters for a lens which demonstrates an alteration in base curve to achieve the desired power.[6]

Because the peripheral cornea-lens contour relationship is so critical in determining the final effective power of the lens, the keratometer readings are virtually useless in determining the best fit lens. The keratometer is effective only in monitoring corneal changes induced by soft lens wear.[6]

The corneas of B & L Soflens patients were monitored for diurnal variations.[8] The average horizontal curvature was found to vary less than 0.25 diopters, while the verticle curvature varied slightly more than 0.25 diopters. These results indicate that there is considerably less diurnal corneal change with B & L Soflens than there is for the conventional hard contact lens wearers. Other studies of diurnal variation of corneas on subjects not wearing contact lenses do not show any significant difference from those wearing Soflens.[11] Using the PEK, Tomlinson also found the corneal changes to be very slight. He also demonstrated that small changes can occur in the corneal shape without being transmitted to the front surface of the contact lens.[8]

The intent of this project is to measure corneal asphericity by means of the Wesley-Jessen System 2000 photokeratoscope and also to investigate the presence or absense of a covariation in acuity with the standard Snellen chart.

The data will be used to answer the following questions:

1. Is daytime visual acuity altered by distortions by asphericity (the shape factor) or changes in asphericity?

2. Is there a significant difference in the magnitude of the resultant between the group achieving 20/20 acuity and that group not achieving 20/20 acuity and not attributable to a power error?

3. Does a covariation between asphericity and visual acuity over time fail to exist?

METHODS

Eleven subjects presenting themselves at the Pacific University College of Optometry for soft contact lenses were selected to participate in this study. Their ages ranged from sixteen to forty years. Keratometry values ranged from 41.50 KD to 45.00 KD for the flattest meridian. Corneal cylinder ranged from .12 KD to 1.75 KD. The spherical refractive error ranged from -1.25 diopters to -6.00 diopters with refractive astigmatism ranging from zero to -.75 diopters with the rule. All refractive errors are referenced to the spectacle plane.

This sampling was drawn from the general clinic population where the examination and the selection of the best fit lens was being done by the intern who was assigned to that case.

Of the original eleven subjects, four were unable to continue in the study due to damaged or lost lenses or for medical reasons. Therefore, only seven subjects were able to participate for the full two and one-half month period.

METHODS AND MATERIALS

Visual acuity was determined by the use of standard optometric equipment which included the projected Snellen chart in a twenty-foot-long room at an ambient light level of seven foot-candles. The base line acuity was determined during the initial examination. At the time of initial dispensing, visual acuity was measured after a suitable adaptation period had elapsed. Acuity was remeasured during each progress evaluation as the initial step. The Wessley-Jessen System 2000 Photokeratopscope was used to measure the corneal topography. This system describes how the surface contours depart from being spherical in the major and minor meridians. Measurements of each eye were taken twice during each examination period. Upon arrival at the clinic, a keratogram of the lens in situ was taken. Following the progress evaluation, a second keratogram was taken of the eyes with the lenses removed. The visual acuity measurements and keratograms were taken during periodic examinations over a two and one-half month period. Any observed relationship between the corneal and hydrogel lens shape factors was and will be referred to as the resultant.

In addition to the contact lens patients, three student interns were selected to participate in a reliability group. All had visual acuity correctable to 20/15, corneal cylinder ranging from .50 KD to 1.75 KD, and refractive cylinder ranging from -.25 to -1.25 diopters with the rule. None of the three had worn contact lenses in the past three years; and there was no pathology present. Four successive keratograms were taken of each eye in a period of a few minutes. These keratograms were analyzed along with those of the contact lens patients to determine the reproducibility of measurements and the amount of variation in a normal cornea not having worn a contact lens.

RESULTS

The scatterplots in Figures 1 and 2 graphically depict the magnitude of change in asphericity of the major refracting surface of the eye while no measurable change in visual acuity occured. The ordinate represents visual acuity in decimal notation while the abscissa represents the changes in shape factor that occured over the time period monitored. Figure 1 represents the data taken from our control group who wore no contact lenses, while Figure 2 represents the data taken from the experimental group without the contact lens. Figure 3 then represents the same data taken from the experimental group with the soft contact lens in place. Part A of each figure is the representation of the change in shape factor of the horizontal meridians; and Part B contains the same information for the vertical meridians. Part C represents the change in anterior surface toricity over time as determined by the difference between the horizontal and vertical meridian shape factors as a function of time.

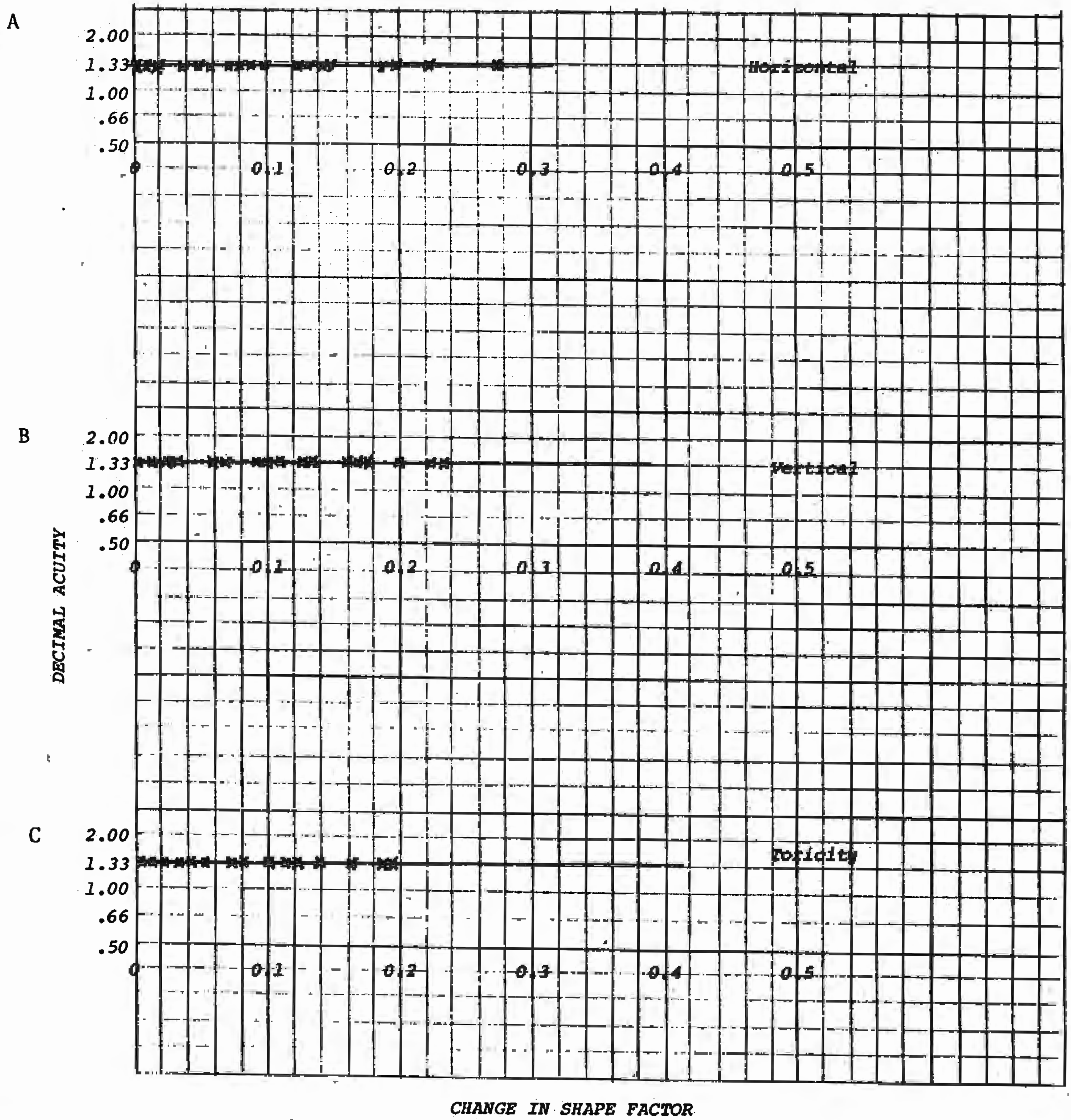

A
B
C
2.00
1.33
1.00
.66
.50
0
0.1
0.2
0.3
0.4
0.5
Horizontal
Vertical
Toricity
DECIMAL ACUITY
CHANGE IN SHAPE FACTOR

Figure 1

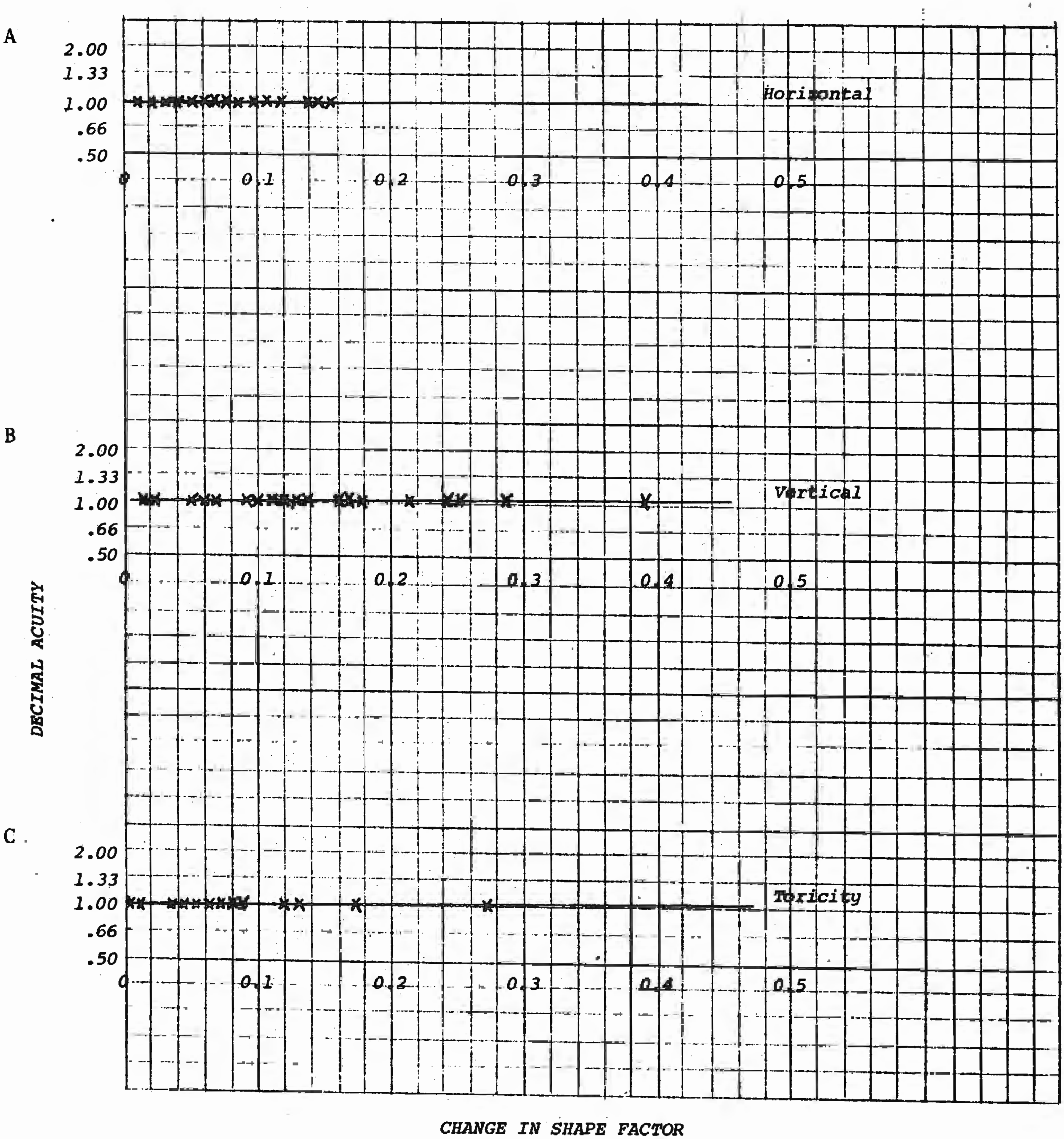

A
2.00
1.33
1.00
.66
.50
Horizontal
0
0.1
0.2
0.3
0.4
0.5
B
2.00
1.33
1.00
.66
.50
Vertical
0
0.1
0.2
0.3
0.4
0.5
C
2.00
1.33
1.00
.66
.50
Toricity
0
0.1
0.2
0.3
0.4
0.5
DECIMAL ACUITY
CHANGE IN SHAPE FACTOR

FIGURE 2

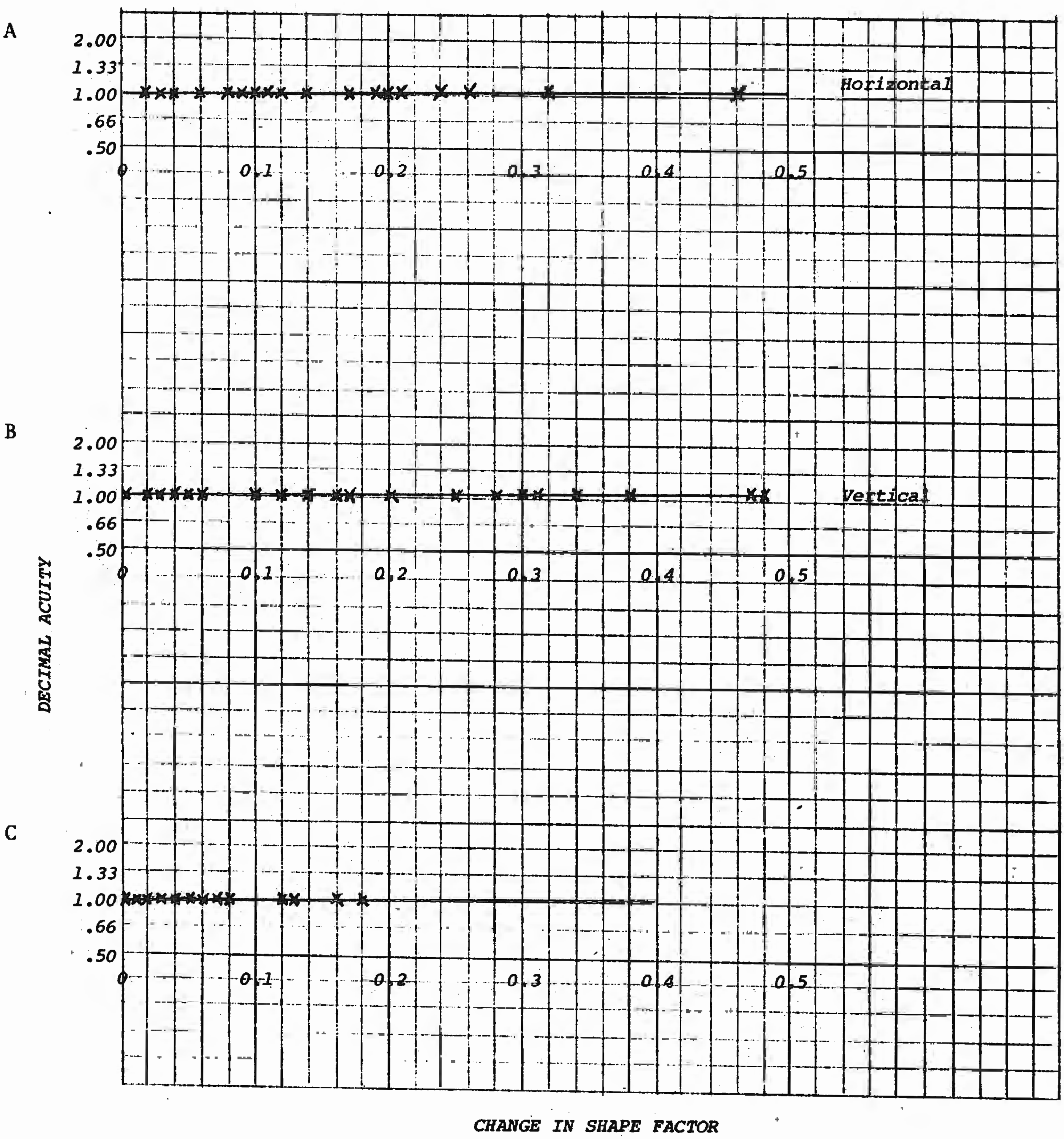
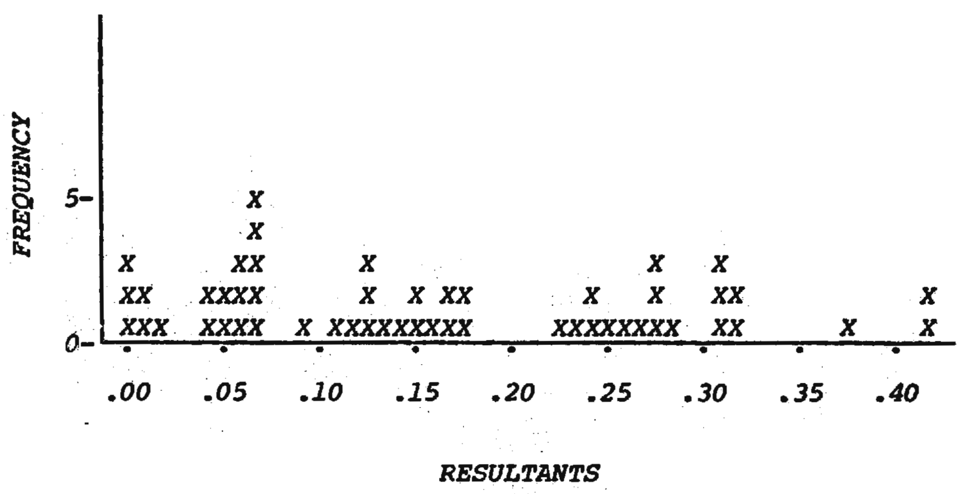

A
2.00
1.33
1.00
.66
.50
0
0.1
0.2
0.3
0.4
0.5
Horizontal
B
2.00
1.33
1.00
.66
.50
0
0.1
0.2
0.3
0.4
0.5
Vertical
C
2.00
1.33
1.00
.66
.50
0
0.1
0.2
0.3
0.4
0.5
DECIMAL ACUITY
CHANGE IN SHAPE FACTOR

FIGURE 3

Visual inspection of these graphs shows a notable range in shape factor for all three conditions. While the range varies considerably, the difference in the three conditions for the horizontal, vertical and difference categories was not significant as determined by the student t test.

Subjects in this study reporting less than normal (20/20) visual acuity with hydrophilic lenses achieved 20/20 or better during the course of the over-refraction. Therefore, Question Number 2 could not be dealt with as proposed. Within this experimental group, the magnitude of the resultant for both meridians had a range of 0.00 to 0.42. This suggests that the major refracting surface can fluctuate in asphericity within this range and not alter the measurable daytime visual acuity.



In answering Question Number 3, no covariation of asphericity and visual acuity could be found within this group. Figure 4 shows that the range of asphericities and visual acuities recorded at the time of the first keratograms was

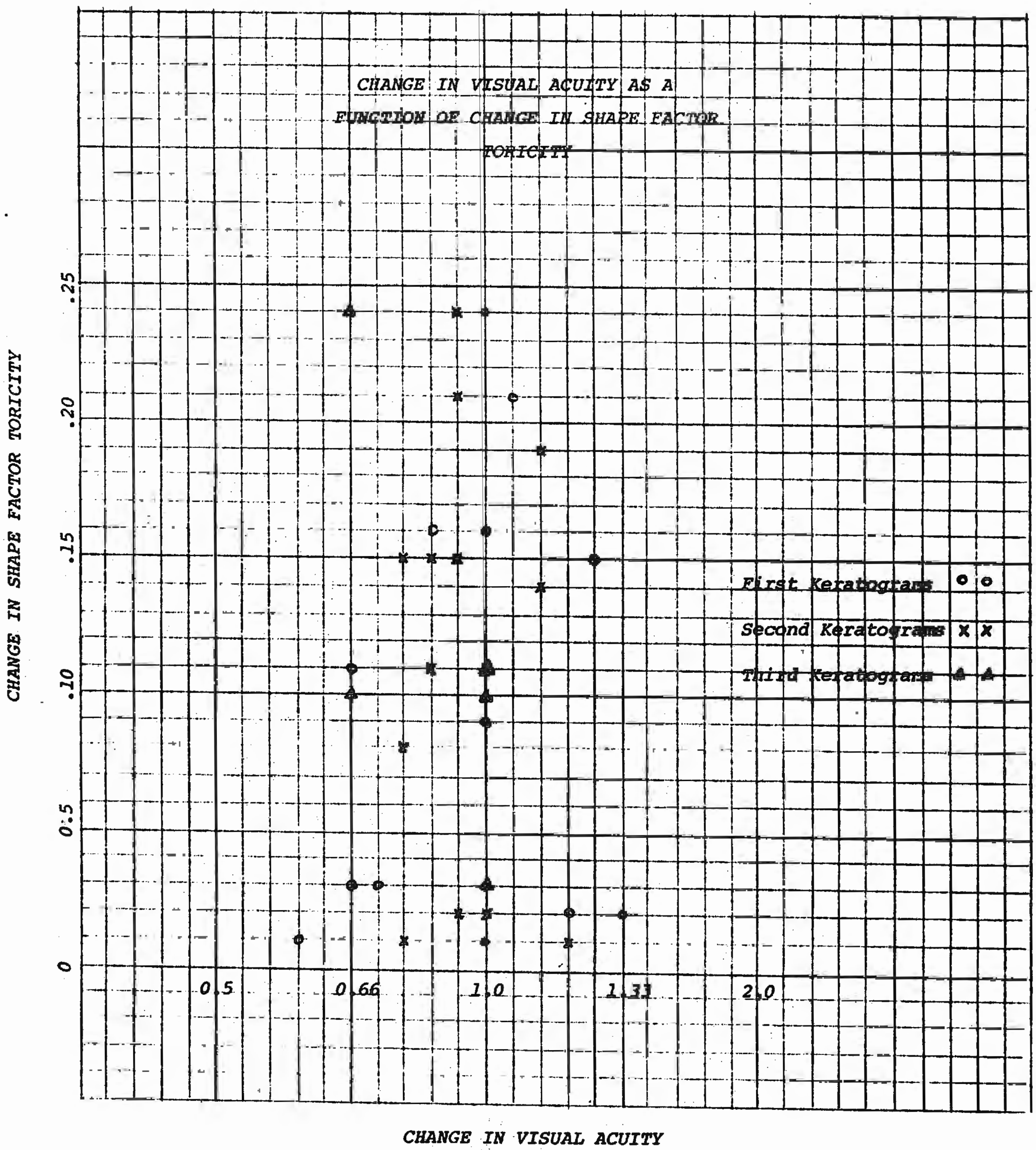

CHANGE IN VISUAL ACUITY AS A
FUNCTION OF CHANGE IN SHAPE FACTOR
TORICITY
First Keratograms
Second Keratograms
Third Keratograms
CHANGE IN SHAPE FACTOR TORICITY
.25
.20
.15
.10
0.5
0
0.5
0.66
1.0
1.33
2.0
CHANGE IN VISUAL ACUITY

FIGURE 4

0.01 to 0.24 and 20/15 to 20/30-2 respectively. The range of asphericities and visual acuities at the time of the second keratograms was 0.01 to 0.24 and 20/20 to 20/20-3. Virtually the same range of shape factors and acuities was found at the time that the third keratograms were taken.

Figure 4 indicates that the shape factor of the major refracting surface of the eye-soft lens system and the visual acuity can vary independently of each other. Had a covariation been observed, the graph would show a linear function with a negative slope. Any increase in shape factor toricity should result in - decrease in visual acuity and vice versa.

Figure 5 is a scatterplot relating the change in shape factor to the sphere-equivalent of the over-refraction that was determined within ten minutes of the taking of the keratogram. One quickly sees that the magnitude of anterior surface toricity changes, as determined by shape factors, does not significantly alter the sphere-equivalent of the over-refraction necessary to obtain 20/20 or better acuity.

We must also assume from this that no supplemental power effect has been realized with the ranges of change in shape factor observed in this study.

DISCUSSION

At the outset, this study anticipated that some subjects would have poor visual acuity while wearing hydrophilic contact lenses. The reduced visual acuity was ex-

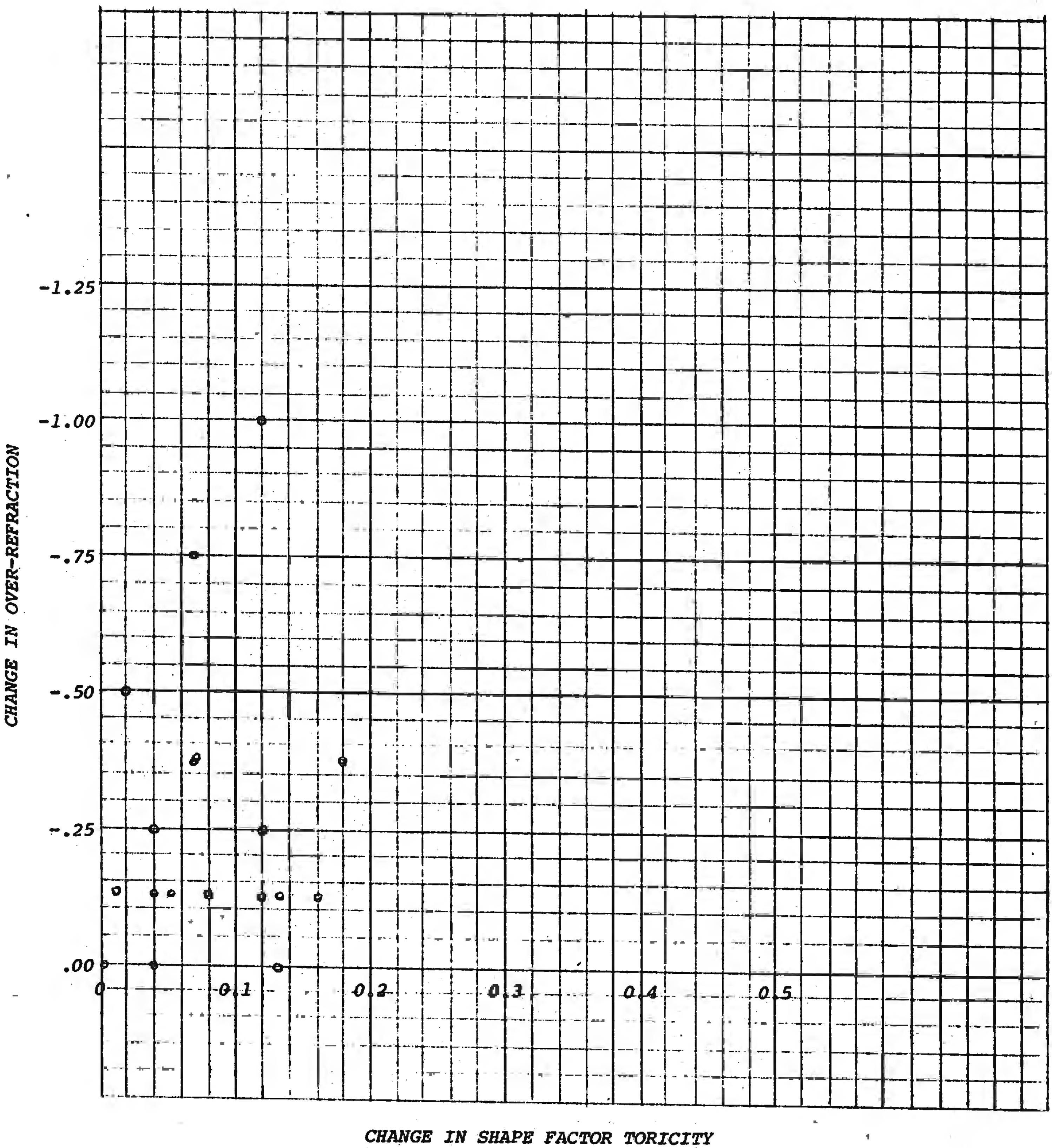

CHANGE IN OVER-REFRACTION
-1.25
-1.00
-.75
-.50
-.25
.00
0
0.1
0.2
0.3
0.4
0.5
CHANGE IN SHAPE FACTOR TORICITY

FIGURE 5

pected to result from distortion of the contact lens in conforming to a peculiarly shaped cornea. A range of corneal asphericity was expected to be found in which the hydrophilic lens could conform with limited distortion and still allow normal 20/20 acuity. Corneal asphericities falling outside this range would not allow the lens to conform without distortion such that normal acuity was unobtainable. Due to distortion of the hydrophilic lens, this lowered acuity could not be corrected by a simple sphero-cylinder over-refraction.

Working with B & L Soflens, Feldman found a range of corneal asphericities compatible with that lens. A successful fit was achieved on 92.6% of the patients with corneal asphericities within this range.[6] This study included B & L Soflens, Hydrocurve II and Naturview lenses and found it was not limited by this range for achieving successful fits with good visual acuity. This could be due in part to several factors such as the lens sizes resulting in various amounts of scleral coverage, the lens design where B & L Soflens is spin cast resulting in aspherical bases while the Hydrocurve and Naturview are lathe cut resulting in spherical bases, and the fitting method where Hydrocurve and Naturview do not include power as a parameter for the physiological fit.

Since all subjects participating in this study were able to achieve good acuity, two groups could not be formed as originally proposed. Although the shape factors and toricity varied markedly, the visual acuity remained stable. This lack of effect was reinforced by a variation of only 0.25 diopters sphere-equivalent in the over-refraction in 75% of the sample.

The inability to form two groups prevented addressing the questions originally put forth since all subjects attained good acuity. One parameter which was not monitored, however, was pupil size. All pupils would have been relatively constricted due to the lighting conditions which would tend to sustain good acuity by blocking the more peripheral light rays.

The significance of this study is that the major refracting surface of the eye-lens system can undergo changes in asphericity with no associated change in daytime acuity. When good acuity cannot be achieved with diagnostic lenses, front surface flexure may be the limiting factor.

Subsequent studies of front surface hydrophilic lens topography and its relationship to visual acuity would do well to consider additional controls such as:

1. Subjects should be limited to those unable to achieve 20/20 visual acuity during diagnostic fitting with a sphero-cylinder over-refraction included.

2. Several different designs of hydrophilic lenses should be fitted to determine the unique influence of a given cornea.

3. Visual acuity should be measured by a more critical method than the Snellen Chart such as the spatial frequency grating.

4. Visual acuity in the dark adapted state should determine the effects of a larger pupil size.

SUPPLEMENTARY DISCUSSION

Figues 6, 7 and 8 graphically depict the lines of best fit as determined from shape factor data taken from the naked cornea and then from the soft lens worn on that same cornea. Figure 6 represents data taken from the horizontal meridian; Figure 7 represents data from the vertical meridian; and Figure 8 represents anterior surface toricity data which is the difference between shape factors for the two meridians.

The slope of the lines representing the three different lenses is similar in that all are approximately 0.20 but with the absolute magnitudes differing markedly. One should expect the Hydrocurve and Naturview lenses to have a shape factor greater than the cornea in both meridians as well as in anterior surface toricity. The Baush and Lomb lens, however, can be expected to yield a shape factor less than that of the cornea and with a reduced amount of toricity. This may be due to the larger diameters, flatter base curves and spherical posterior apical radiuses along with reduced center thicknesses of the Hydrocurve and Naturview lenses. These factors could conceivably allow those lenses to conform more closely to the cornea than the Baush and Lomb lens.

The Baush and Lomb lens repeatedly yielded a decreased shape factor in both meridians as well as in the transferred toricity. Sampling of a larger population of B & L lens wearers may yield a somewhat different outcome; however,

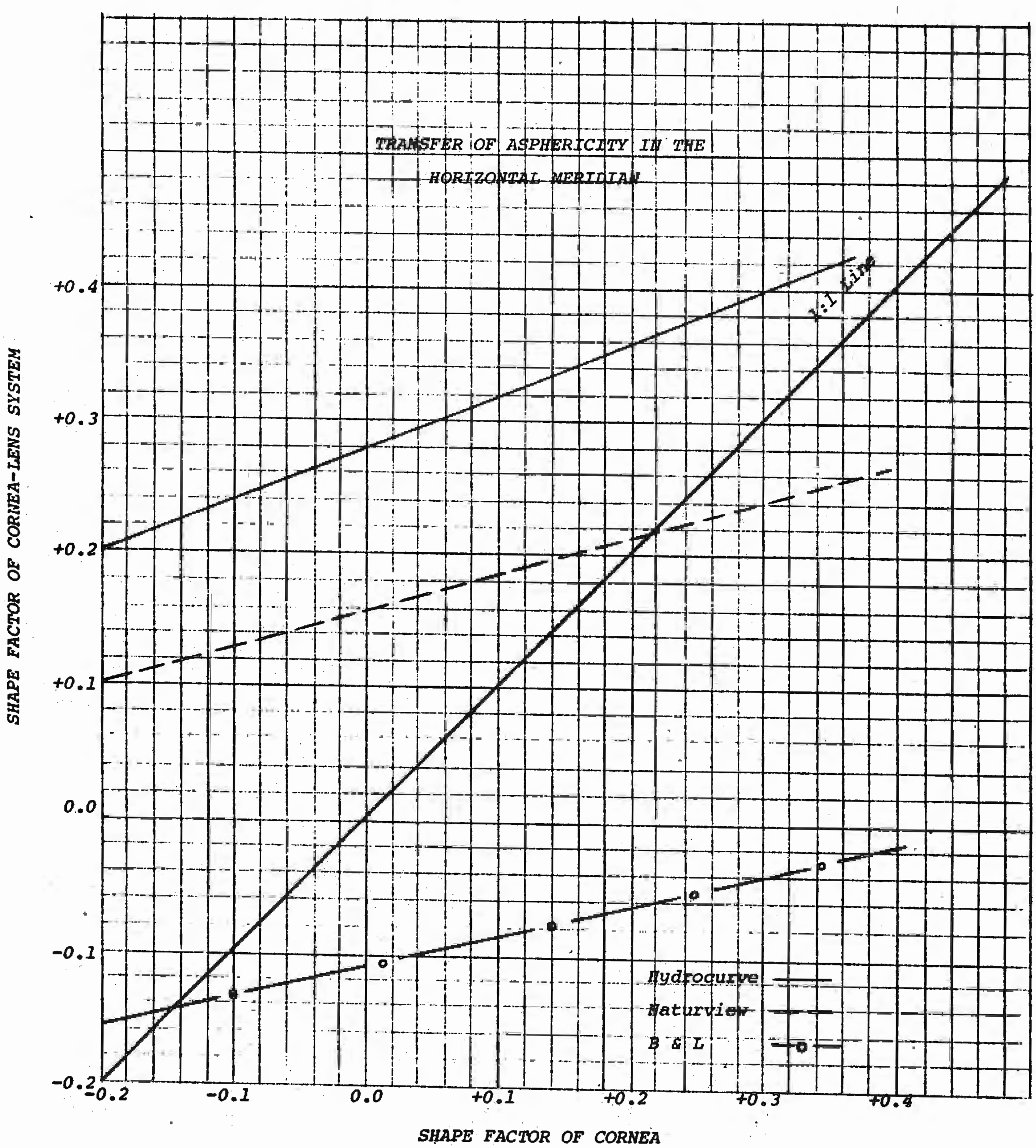

TRANSFER OF ASPHERICITY IN THE
HORIZONTAL MERIDIAN
1:1 Line
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
SHAPE FACTOR OF CORNEA-LENS SYSTEM
-0.2
-0.1
0.0
+0.1
+0.2
+0.3
+0.4
SHAPE FACTOR OF CORNEA
Hydrocurve
Naturview
B & L

FIGURE 6

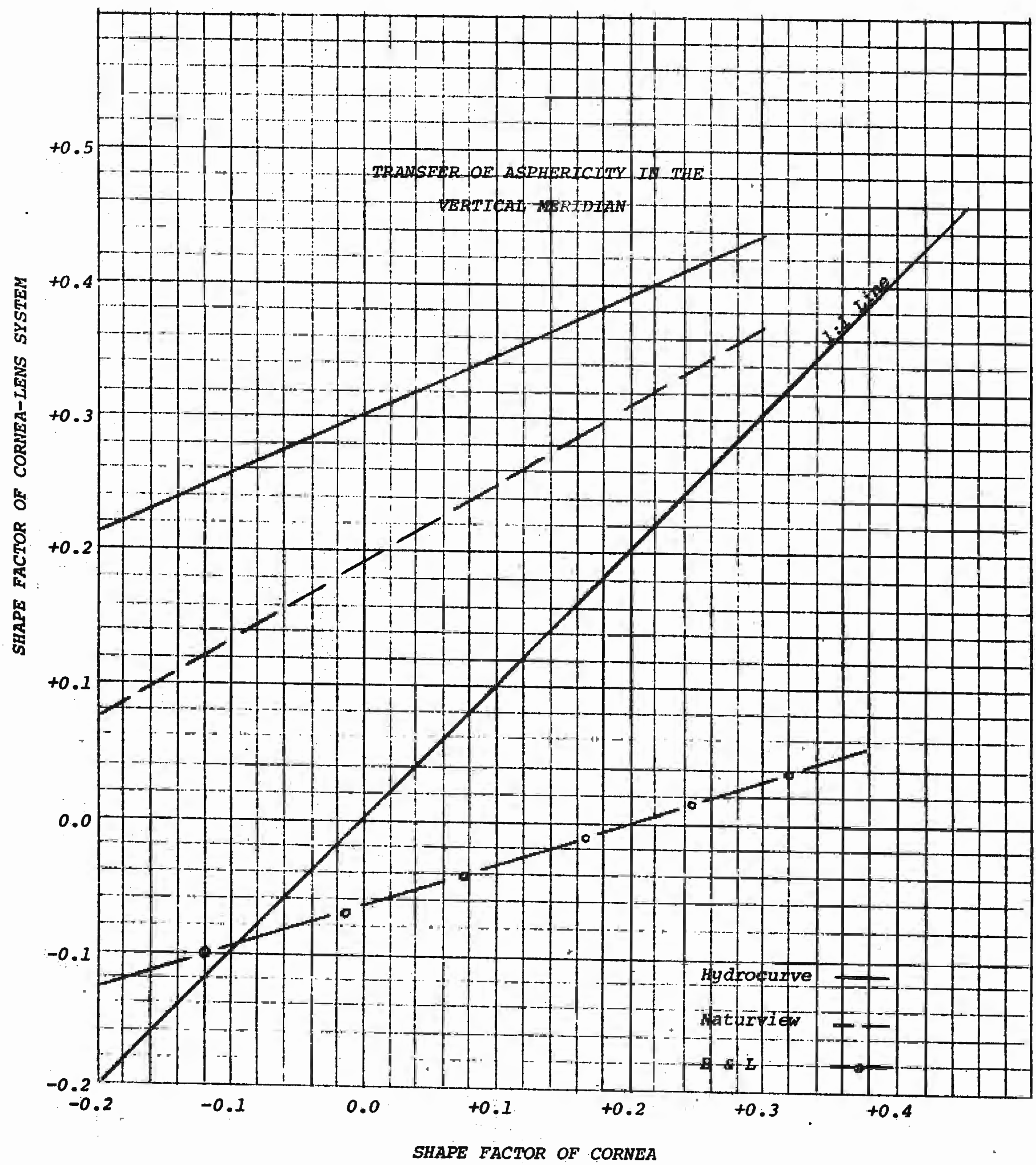

TRANSFER OF ASPHERICITY IN THE
VERTICAL MERIDIAN
1:1 Line
Hydrocurve
Naturview
B & L
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.2
-0.1
0.0
+0.1
+0.2
+0.3
+0.4
SHAPE FACTOR OF CORNEA-LENS SYSTEM
SHAPE FACTOR OF CORNEA

FIGURE 7

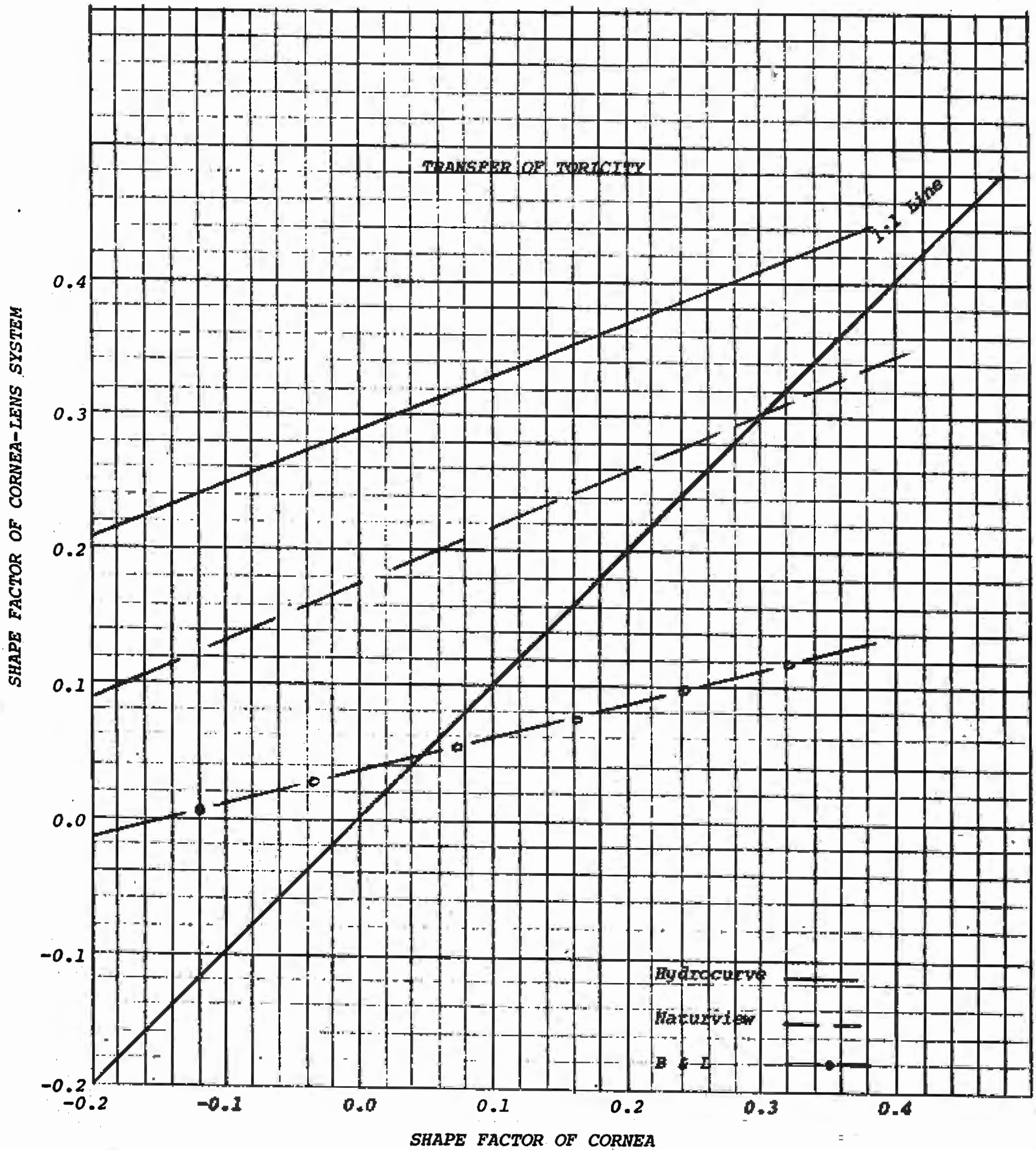

TRANSFER OF TORICITY
1:1 Line
Hydrocurve
Naturview
B & L
SHAPE FACTOR OF CORNEA-LENS SYSTEM
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
SHAPE FACTOR OF CORNEA

FIGURE 8

so this finding should not be taken too seriously.

Figure 9 is a best plot representing transfer of toricity from the cornea to a non-toric hydrophilic lens. Actual data points have been omitted for simplicity. One can quickly see that the Naturview and Hydrocurve lenses both transmit corneal toricity in about the same proportions and in approximately the same magnitudes. We can assume from this data that these lenses would best correct those patients having low refractive cylinder combined with higher corneal cylinder. These lenses would do little to correct those patients having a moderate to high refractive cylinder regardless of the magnitude of corneal cylinder.

Low amounts of corneal cylinder appear to transfer most completely while the magnitude is considerably less with moderate amounts of corneal cylinder. Based upon this observation, one might expect the formation of some amount of tear prism on more highly toric corneas. This phenomena could, therefore, cause some persons to become less astigmatic through the application of hydrophilic contact lenses.

The negative slope calculated for the B & L lens is highly questionable since only four data points were used. Further study should be done to determine the validity of this observation. If this were a reliable and repeatable phenomena, then this might be the better lens to try on high astigmats with high corneal toricity.

Much work quantifying the transfer of corneal cylinder to the anterior surface of the hydrophilic lens to determine

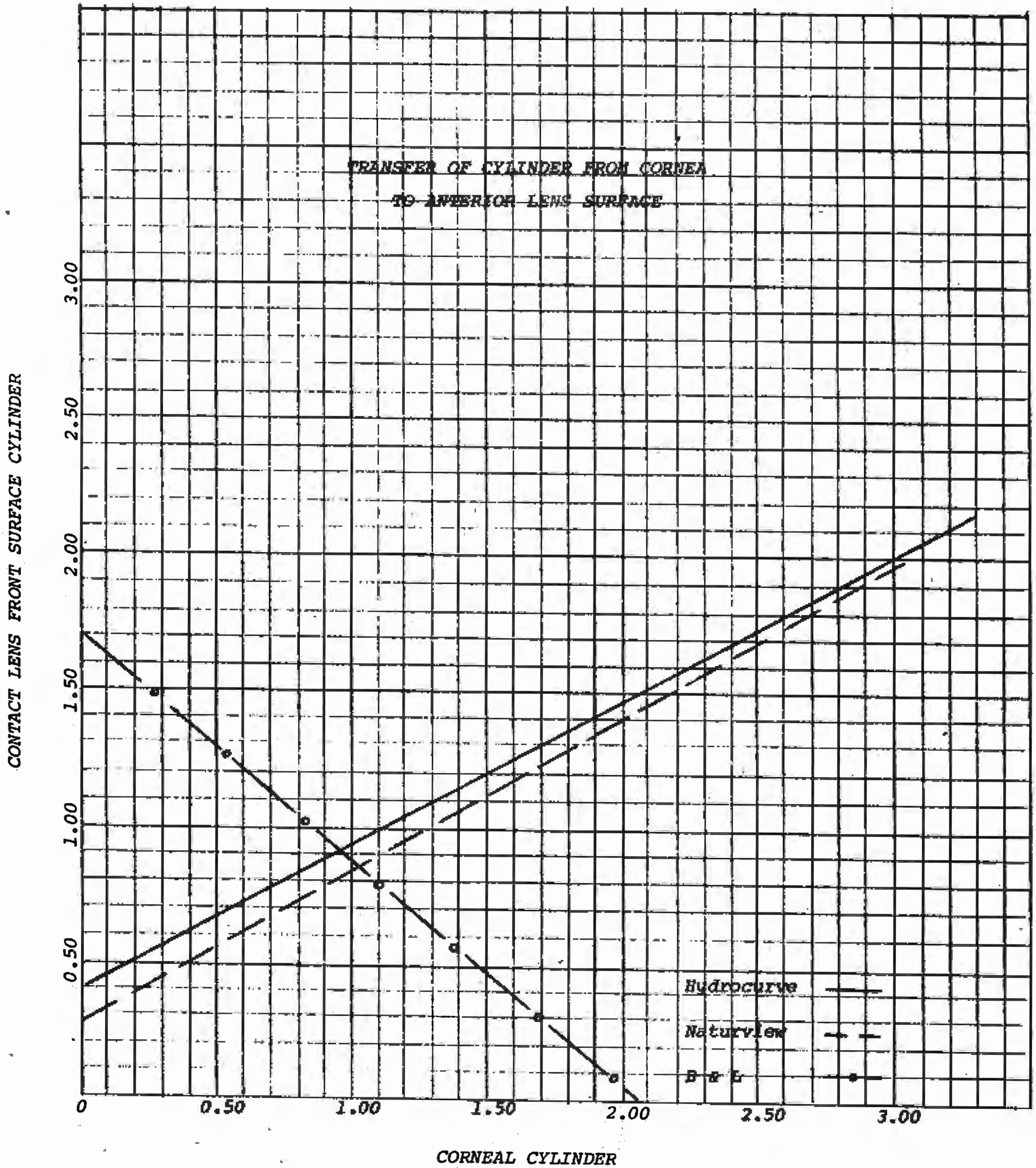

TRANSFER OF CYLINDER FROM CORNEA
TO ANTERIOR LENS SURFACE
CONTACT LENS FRONT SURFACE CYLINDER
3.00
2.50
2.00
1.50
1.00
0.50
0
0.50
1.00
1.50
2.00
2.50
3.00
CORNEAL CYLINDER
Hydrocurve
Naturview
B & L

FIGURE 9

the characteristics of the individual lenses should be done.

It has been reasoned that a soft contact lens can be verified for power by finding the difference between keratometry readings taken over the lens and the keratometry value for the flattest meridian of the naked cornea. Our study included all of the necessary information for this to be dealt with. All of the keratometry readings are those found by the photoelectric keratometer and, therefore, are not the standard ophthalmometer reading. Figure 10 shows a scatterplot of the actual marked power of the lens compared to the power arrived at by finding the difference in K readings. The plot is broken into the three lens types used. All of the powers are related to the 1:1 line. From this it can be seen that the large majority of measured powers are less than the marked lens power. For the Naturview lenses, the range of differences was 0.96 diopters less to 0.96 diopters greater than marked. The B & L Lens showed a range of 0.50 to 1.43 diopters less than marked. The Hydrocurve lens range was 1.83 diopters less to 0.30 diopters greater than marked. This is a gross and unreliable method of verifying the power of hydrophilic contact lenses.

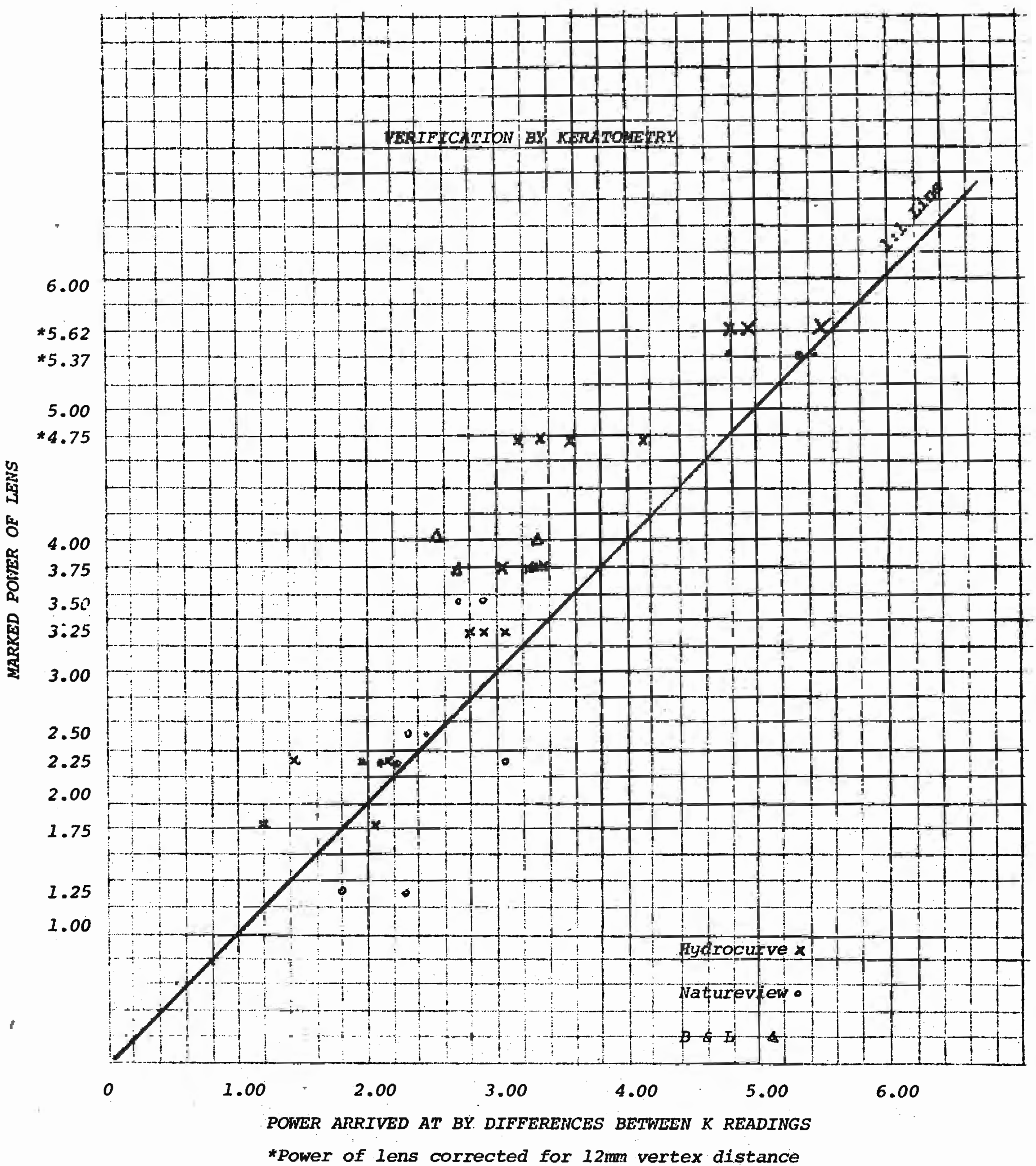

VERIFICATION BY KERATOMETRY
1:1 Line
MARKED POWER OF LENS
6.00
*5.62
*5.37
5.00
*4.75
4.00
3.75
3.50
3.25
3.00
2.50
2.25
2.00
1.75
1.25
1.00
0
1.00
2.00
3.00
4.00
5.00
6.00
Hydrocurve x
Natureview o
B & L Δ
POWER ARRIVED AT BY DIFFERENCES BETWEEN K READINGS
*Power of lens corrected for 12mm vertex distance

FIGURE 10

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