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ORIGINAL ARTICLE

Calibration Error on the Measurement of Back Vertex Power for Contact Lenses with Method Using Focimeter with Manual Focusing

LI RU WANG, JI YAN ZHANG, MSc, and ZHEN YA MA

Optical Engineering Division, China National Institute of Metrology, Beijing, China

ABSTRACT: *Purpose.* The International Standard ISO 9337-1, which sets forth the method for measuring back vertex power of contact lenses with manually focusing focimeters, specifies that test lenses conforming to ISO 9342 may be used to calibrate focimeters on its spectacle lens support, and correction values obtained in this way can be used directly in measuring contact lenses on its contact lens support. This study was conducted because of concern that the method mentioned in ISO 9337-1 is not good enough for the calibration of focimeters used to measure contact lenses. *Methods.* To test the validity of this method, a research group from China National Institute of Metrology (NIM) studied it theoretically and carried out a series of comparison experiments, respectively, with the conventional test lenses conforming to ISO 9342 and test lenses made at NIM (with an expanded uncertainty of 0.025 D). *Results.* The results show that the measurement error between the two calibration methods will exceed 0.50 D if the specification described in ISO 9337-1 is adopted. This error also exceeds allowable tolerances for focimeters and for contact lenses themselves. Experiments and theoretical calculations done by the NIM group show that these errors mainly come from spherical aberration. Vertex error induced by the lens support is not negligible. *Conclusion.* When focimeters are calibrated to find correction values with the method specified in ISO 9337-1, measurement error will not be eliminated if these correction values are used in measuring contact lenses, and the resulting deviation is too large to be ignored. Therefore, special test lenses should be used to calibrate focimeters to find correction values when these focimeters are used to measure back vertex power of contact lenses because contact lenses are a special product being used to correct human vision. (Optom Vis Sci 2002;79:126–133)

Key Words: focimeter, contact lens, back vertex power, spherical aberration, vertex error

Vertex power is an important parameter of contact lenses. Back vertex power of contact lenses is measured traditionally throughout the world by using a manual focusing focimeter (lensometer). To achieve worldwide standardization of this measurement method, the International Standard Organization (ISO) published ISO 9337-1:1999, Contact lenses—Determination of back vertex power—Part 1: Method using focimeter with manual focusing.[1] In ISO 9337-1:1999, a method is specified for the calibration of focimeters by using test lenses specified in ISO 9342:1996, Optics and optical instruments—Test lenses for calibration of focimeters.[2]

There are many differences in mechanical and optical design among the different models of manual focusing focimeters. In general, a focimeter may be used to measure both spectacle lens and contact lens. Such a focimeter is designed with two lens supports. One is for the measurement of spectacle lenses and has a diameter of 6 to 9 mm. The other is for the measurement of contact lenses with a diameter about 4.5 mm. The distance between a spectacle lens and the cornea of eye is about 12 mm, but a contact lens is used directly in contact with the cornea. The front and back surface radius of curvature of a spectacle lens are chosen to produce the desired vertex power while optimizing aberrations at the various points of gaze and giving a cosmetically pleasing form to the lens. However, the back surface radius of contact lenses is required to approximately fit the surface of the cornea.

Due to the radically different forms of these two lens types, it is not clear whether a focimeter calibrated for spectacle lenses measurement will measure contact lenses accurately. To investigate this question, research and analysis on the measurement of back vertex power for contact lenses have recently been carried out in China at the National Institute of Metrology (NIM). The results show that a focimeter calibrated with test lenses specified in ISO 9342 will produce measurement errors when used to measure contact lenses.

BACKGROUND ON THE RELEVANT INTERNATIONAL STANDARDS

ISO 9342:1996, Optics and Optical Instruments—Test Lenses for Calibration of Focimeters

ISO 9342:1996[3] gives specifications, in detail, on the definitions of back vertex power, reference wavelength, and the design requirements and recommendations of test lenses for focimeters. These specifications include the following: (1) The reference wavelength may be chosen to be either 546.07 or 587.56 nm. (2) The material from which the lenses are made is crown glass with an index of refraction $n_d = 1.523 \pm 0.002$ or $n_e = 1.525 \pm 0.002$.

To minimize the influence of spherical aberration, it is required that the curvature of the back surface and the center thickness of the test lenses should approximately correspond to those of common spectacle lenses in the market; the focimeter is calibrated under conditions closely matching those under which spectacle lenses are measured. The thickness specified for the test lenses is sufficient so that the lens surface is stable and can be precisely manufactured.

ISO 8598, Optics and Optical Instruments—Focimeters

ISO 8598[2] specifies relevant definitions and tolerances for focimeters, which includes the following: (1) The definition of back vertex power is the reciprocal of the paraxial value of the back vertex focal length measured in meters. (2) The vertex power tolerances for a focimeter with a measuring range of 0 to ±20 D range from ±0.06 to ±0.18 D.

ISO 9337-1, Contact Lenses—Determination of Back Vertex Power—Part 1: Method Using Focimeter with Manual Focusing

ISO 9337-1[1] adopts the definition of back vertex power described in ISO 8598. It specifies the calibration method for focimeters, the size of lens support to be used for contact lenses, and the 8-mm back surface radius of the lens in accordance with the change in the size of central aperture of lens support. It also specifies the measuring method with which to determine the back vertex power of contact lenses. For the purpose of calibration, conventional test lenses conforming to ISO 9342 may be used. With the replacement of contact lens support, correction values obtained by using conventional test lenses (ISO 9342) on spectacle lens support can be used directly when measuring contact lenses.

The calibration method specified in ISO 9337-1 requires that each conventional test lens should be measured three times with the focimeter under calibration, then the mean power value calculated. The back vertex power of each test lens set is known to ±0.01 D. The mean power measured by the focimeter is subtracted from the known actual power of the test lenses, and the difference thus found is the correction value. A calibration curve is then created by using the correction values. It is recommended that the calibration curve should be created by performing a quadric best-fit from the correction values. The value of the calibration curve for the measured power is then to be added to the measurement value taken by the focimeter to give a corrected back vertex power of unknown lenses.

Motivation for this Study

After reviewing the above specifications, the NIM group was concerned that the method conforming to ISO 9337-1 was not suitable to successfully calibrate a focimeter used to measure contact lenses for following reasons.

1. The back surface radius of curvature for contact lenses is much steeper than that of spectacle lenses. The vertex error induced, when the contact lens rests on the support ring, may cause more than a negligible error.
2. There might be other optical effects (such as spherical aberration) induced by the highly curved form of the contact lens, which cannot be accounted for through calibration with the spectacle form lens.
3. In addition, we wondered whether the special test lenses of optical glass made at the NIM, with back surface radius of curvature corresponding to those of common contact lenses (described below), are suitable for general use.

METHODS

Special Test Lenses

To test our hypothesis, the NIM group developed special test lenses for contact lenses. The special test lenses consists of eight lenses with nominal back vertex power of −20.00, −15.00, −10.00, −5.00, +5.00, +10.00, +15.00, and +20.00 D. Therefore, the selection of powers and number of test lenses is in accordance with the specifications of ISO 9337-1.

Parameters in Design

The material used for the special test lenses is optical crown glass with refractive index $n_e = 1.528$. We designed the lenses to have specified powers for a reference wavelength of 546.07 nm. The central thickness of the lenses is about 1 mm. The free aperture diameter of the lenses is about 8 mm. The major difference from conventional test lenses specified in ISO 9342 is the back surface radius: the NIM choose it as 7.942 mm, which is approximately equal to the front surface radius of the cornea for the human eye and also is in accordance with the specifications of ISO 9337-1. So these special test lenses have the form of common contact lenses.

Calculation of Back Vertex Power

Following the definition of vertex power in ISO 9342, we took the measured parameters of special test lenses, which include the curvature radius of front surface (R_1), the curvature radius of back surface (R_2), the central thickness (t), and the refractive index (n) of optical glass, into the calculation formula for vertex power precisely. The back vertex power can be obtained from the paraxial ray tracing equations, listed below:

$$F_1 = (n - 1)/R_1$$

$$F_2 = (1 - n)/R_2$$

$$K = 1/(1 - tF_1/n)$$

$$F_V = KF_1 + F_2$$

where F_1 is the front surface power of the contact lens (the surface in contact with air), with unit D; F_2 is the back surface power of the contact lens (the surface in contact with cornea), with unit D; K is the vertex correction factor of the contact lens that vertex corrects the front surface power into the plane of the back surface; and F_V is the back vertex power of contact lens, with unit D.[a]

The Actual Power of Special Test Lenses

Based on the precisely measured parameters of R_1, R_2, t, and n, we obtained the calculated back vertex powers, which we called actual powers of special test lenses. They are listed in Table 1.

Expanded Uncertainty of Special Test Lenses

We undertook an analysis on the expanded uncertainties of the special test lenses as follows[4]:

Calculation of the Components of Uncertainty. The standard uncertainty $u(R_1)$ issued from the curvature radius of front surface R_1 (for the lens master ball and the interference rings) is calculated as shown:

The standard uncertainty $u(R_{1a})$ of the lens master ball: $u(R_{1a})$ = 0.000125 mm.

The standard uncertainty $u(R_{1b})$ of the one interference ring at 10 mm diameter: $u(R_{1b})$ = 0.000282 to 0.00141 mm.

The standard uncertainty $u(R_1)$: $u(R_1) = [u^2(R_{1a}) + u^2(R_{1b})]^{1/2}$ = 0.000309 to 0.00142 mm.

The standard uncertainty $u(R_2)$ issued from the curvature radius of back surface R_2 (for the lens master ball and one interference ring at 10 mm diameter): $u(R_2)$ = 0.000537 mm.

The standard uncertainty u(t) issued from the central thickness t: u(t) = 0.001 mm.

The standard uncertainty u(n) issued from the refractive index of optical glass n: u (n) = 0.000025.

TABLE 1.
Nominal and actual values of special test lenses.

Nominal Value (D)	Actual Value (D)
+20	+19.999
+15	+14.989
+10	+9.998
+5	+4.991
−20	−20.004
−15	−15.003
−10	−10.014
−5	−5.001

Combined Standard Uncertainty

Using the partial differential equation of the standard formula, we can calculate the combined uncertainty from all four components of uncertainty:

$$u_1 = c_1u(R_1);\ u_2 = c_2u(R_2);\ u_3 = c_3u(t);\ u_4 = c_4u(n)$$

$$u_c^2(Fv) = u_1^2 + u_2^2 + u_3^2 + u_4^2$$

where

$$c_1 = -K^2F_1/R_1;$$

$$c_2 = -F_2/R_2;$$

$$c_3 = K^2F_1^2/n;$$

$$c_4 = (K^2F_1 + F_2)/(n - 1) - K^2F_1^2t/n^2.$$ [b]

Then the combined standard uncertainty $u_c = (u_1^2 + u_2^2 + u_3^2 + u_4^2)^{1/2}$ = 0.0074 - 0.0081.

Expanded Uncertainty

The expanded uncertainty U is obtained by multiplying the combined standard uncertainty u_c by a coverage factor k. If we take the coverage factor as 3, which will produce an interval having a level of confidence of approximately 99%, then the expanded uncertainty U = $3u_c$ = 0.022 to 0.024 D. Therefore, the expanded uncertainties of the NIM special test lenses are within 0.025 D.

Equipment and Measurement Conditions

We tested focimeters that represent types used commonly in the Chinese market: LM-P6 (Topcon, Tokyo, Japan) and LM-770 (Nidek, Gamagori, Japan). These focimeters all have digital displays and are projection focimeters with manual focusing. These focimeters have a cross target in the projection screen, and the reading step is 0.02 D. Manually focusing projection focimeters are the most commonly used for measurement of contact lenses throughout the world. We also used manual focusing eyepiece focimeters because this type of focimeter is also found in practice: LM-8 (Topcon, Tokyo, Japan), LM-380 (Nidek, Gamagori, Japan), and QY-III (Jingyi, Chongqing, China). These types of focimeters measure in 0.12 D steps and have rotating drum scales to increase the resolution of reading. A set of conventional test lenses (U = 0.02 D) conforming to the specifications of ISO 9342 was also used. Both the conventional test lenses and the special test lens for contact lens made by the NIM were measured on each focimeter to find correction values using the method of ISO 9337-1. The NIM special test lenses were measured on each focimeter using its contact lens support to obtain a series of correction values called A. The corresponding calibration curves were called curves A. The conventional test lenses were measured on each focimeter using its spectacle lens support to obtain another series of correction values called B. The corresponding calibration curves were called curves B.

[a] All the measured parameters mentioned above are traceable to the National Primary Standard of Measurement in China.

[b] $c_1 = \delta Fv/\delta R_1$; $c_2 = \delta Fv/\delta R_2$; $c_3 = \delta Fv/\delta t$; $c_4 = \delta Fv/\delta n$. K is the vertex correction factor of the contact lens.

Elimination of the Random Error in Measurement

When using focimeters with manual focusing to measure the back vertex power of contact lenses, the focusing error and reading error caused by operators cannot be avoided completely in measurement. Naturally, some operators can make more repeatable measurements than others. Therefore, we used five operators who made measurements on each focimeter model in a random order. Each test lens was measured by an operator five times, who carefully centered the lens to zero prism and ensured that it was not titled, on a given focimeter. From each such set of measurements, a mean value and a difference from the mean was found.

To remove the error of measurement induced by different operators, we took the average based on each independent mean from each operator as the total mean power for a given lens measured with a given focimeter. Thus, the random focusing and reading error of each operator was eliminated. Consequently, we were able to evaluate the error statistically in measurement for each focimeter over a range of powers. We were also able to evaluate the differences between the total mean power and each operator's mean power. We found in this way that the difference is controlled to within ±0.06 D, thus assuring the reliability of the measuring results.

RESULTS

Table 2 gives correction values A, correction values B, and the differences between A and B for each focimeter tested in the study. Correction value A is the deviation of the mean measured powers of the NIM special test lenses for each focimeter tested in the study from the actual powers of these lenses. Fig. 1a shows the calibration curves for each focimeter, created by fitting correction values A to a quadratic function. Correction value B is the deviation of the mean measured powers of the conventional lens series (test lenses

TABLE 2.
Correction value A, correction value B, and the differences between A and B for each lens and focimeter tested in the study.

Nominal Value (D)	Actual Value (D)		Model (Serial No.)						
			LM-380 (10799)	LM-770 (23359)	LM-8 (3410452)	LM-P6 (816610)	LM-P6 (816967)	QY-III (0011004)	QY-III (0011003)
−20	−20.004	Correction A	0.52	0.39	0.59	0.77	0.75	—	—
		Correction B	−0.03	−0.07	0.00	0.07	0.12	—	—
		Differences	0.55	0.46	0.59	0.70	0.63	—	—
−15	−15.003	Correction A	0.44	0.37	0.48	0.64	0.52	0.42	0.37
		Correction B	−0.02	−0.01	0.02	0.05	0.02	0.00	0.00
		Differences	0.46	0.38	0.46	0.59	0.50	0.42	0.37
−10	−10.014	Correction A	0.35	0.29	0.38	0.51	0.43	0.25	0.28
		Correction B	−0.01	−0.01	0.03	0.05	0.02	−0.01	0.01
		Differences	0.36	0.30	0.35	0.46	0.41	0.26	0.27
−5	−5.001	Correction A	0.26	0.23	0.22	0.32	0.30	0.12	0.10
		Correction B	0.00	0.00	0.03	0.06	0.01	0.00	−0.01
		Differences	0.26	0.23	0.19	0.26	0.29	0.12	0.11
0	0	Correction A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Correction B	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Differences	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	4.991	Correction A	−0.14	−0.20	−0.15	−0.28	−0.33	−0.30	−0.25
		Correction B	0.03	0.01	0.04	0.01	0.00	0.01	−0.05
		Differences	−0.17	−0.21	−0.19	−0.29	−0.33	−0.31	−0.20
10	9.998	Correction A	−0.23	−0.36	−0.22	−0.33	−0.34	−0.45	−0.37
		Correction B	0.06	0.00	0.07	0.04	0.02	−0.01	−0.05
		Differences	−0.29	−0.36	−0.29	−0.37	−0.36	−0.44	−0.32
15	14.989	Correction A	−0.26	−0.40	−0.20	−0.37	−0.28	−0.51	−0.47
		Correction B	0.11	0.00	0.07	0.03	0.06	0.00	−0.02
		Differences	−0.37	−0.40	−0.27	−0.40	−0.34	−0.51	−0.45
20	19.999	Correction A	−0.27	−0.40	−0.20	−0.31	−0.21	—	—
		Correction B	0.23	0.05	0.20	0.06	0.17	—	—
		Differences	−0.50	−0.45	−0.40	−0.37	−0.38	—	—

conforming to ISO 9342) for each focimeter tested in the study from the actual powers of these lenses. Fig. 1b shows the calibration curves for each focimeter created by connecting correction values B orderly. Fig. 1c shows the calibration curves for each focimeter created by connecting the difference between A values and B orderly. For test lenses with nominal values of ±5 D, the difference is about 0.25 D. By ±20 D, the difference has increased to 0.42 to 0.59 D. This illustrates the fact that the calibration curve derived from adopting provisions of ISO 9337-1 would not adequately correct measurement errors found in measuring contact lenses.

DISCUSSION

Theoretical Verification

To understand the measurement results of this study more fully, the NIM group performed the following theoretical analysis to estimate the effects of vertex error and spherical aberration.

Calculation of Vertex Error

Focimeters measure the back vertex power of lenses referenced to a fixed position along the optical axis of the instrument. The back vertex of a lens under measurement should be coincident with this position. If it is not, a vertex error is said to exist, and measuring error will be induced on the measured power value. Correction values A, obtained by calibrating focimeters with the NIM special test lenses on its contact lens support, were used to calculate vertex error when lenses with 7.942-mm back surface radii were measured on the focimeter with contact lens support. This was done by fitting the correction values, in best least-squares fashion, to a second-order polynomial, thereby creating a polynomial expression for measurement error given in diopters. This is the method recommended in ISO 9337-1. The fitting coefficient of the second-order term was then used as an estimate of the vertex error. This can be done because measurement error for a given vertex error, as a function of power, is quadratic in form. Dimensional analysis also shows that the unit of the second-order coefficient must be that of length if the product of the coefficient and the correction value squared is to have units of diopter. Vertex errors of 0.3 mm ~ 0.7 mm were found in this way for the seven focimeters used in this study. Thus, we have taken 0.5 mm as a representative vertex error to calculate the corresponding deviation of vertex power derived from it.

The relationship between vertex error and power deviation could be shown by the following equation: $\Delta F_V = -F_V^2 \Delta X$, where ΔF_V is power deviation; ΔX is vertex error; and F_V is the back vertex power of measured contact lens. The results show that the biggest deviation on the measurement of back vertex power caused by vertex error is about 0.20 D, which occurred on lenses whose nominal back vertex power is ±20 D (Fig. 2).

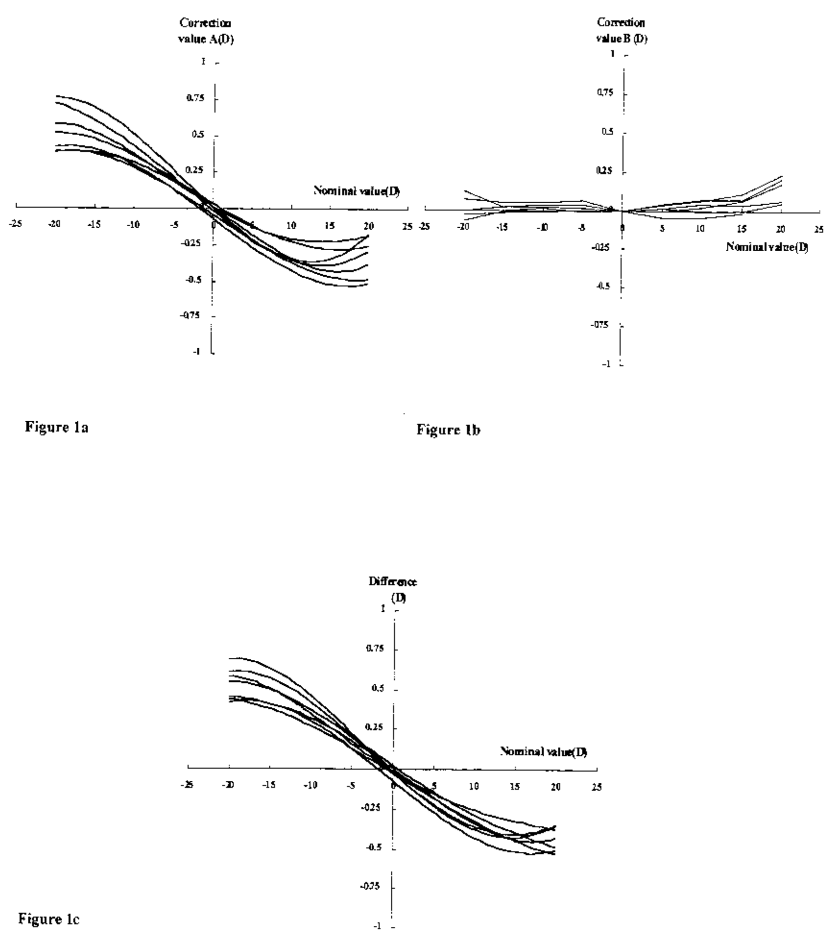

Figure 1a

Figure 1b

Figure 1c

FIGURE 1.

a: Correction value A with the NIM special test lenses on different focimeters. b: Correction value B with conventional test lenses on different focimeters. c: Differences between two correction values A and B.

Calculation of the Effects of Spherical Aberration

Contact lenses are highly meniscus in form, so they will exhibit significant spherical aberration when focusing a collimated beam of light in the condition with air interface on each lens surface. To estimate the effect of this aberration on the selection of best focus in measuring contact lenses with a focusing focimeter, we first calculated, using ray tracing methods, the paraxial back vertex focal length and the marginal back vertex focal length for each lens of the special test lens series by using the measured surface radii of curvature of the lens, the index of refraction of the optical glass, and the measured central thickness. The aperture radius used to specify the marginal ray was 2.25 mm, which is half the diameter of the specified contact lens support ring with clear aperture.

We then made the assumption that the optimum image plane lies approximately halfway between the marginal ray focus and the paraxial ray focus (Fig. 3).[5] This focal length was then converted to a dioptric value, and this dioptric value was used as the expected value of back vertex power found by the focimeter. These calculations show that the measurement vertex power deviation caused by spherical aberration is substantial. It is up to 1.00 D (Fig. 4).

Comparison of Measurement Results with Theoretical Calculation

The theoretically calculated value of measurement error obtained by combining the above two errors is mainly in accordance with the measurement results (Fig. 5). Thus, the theory analysis accounts for most of the measurement error found experimentally and supports the view of the NIM group that the calibration method specified in ISO 9337-1 is inadequate.

Analysis of Measuring Results on Asymmetric Effects

The measurement results of this study show the very interesting finding that different focimeters have different asymmetric correction values from positive to negative power (see correction values A in Table 2 and Fig. 1a). To understand these effects completely, we need go deeper into analysis.

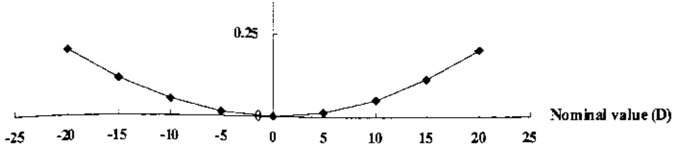

FIGURE 2.
Correction values on vertex error.

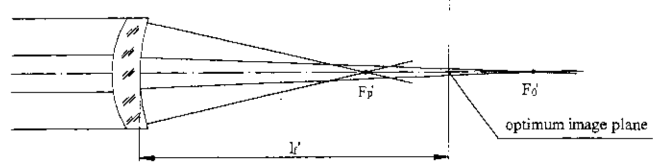

FIGURE 3.
Optimum image plane. F_p' is the image point of the peripheral rays; F_0' is the image point of the paraxial rays; l_f' is the distance of the back surface vertex of lens from the optimum image plane.

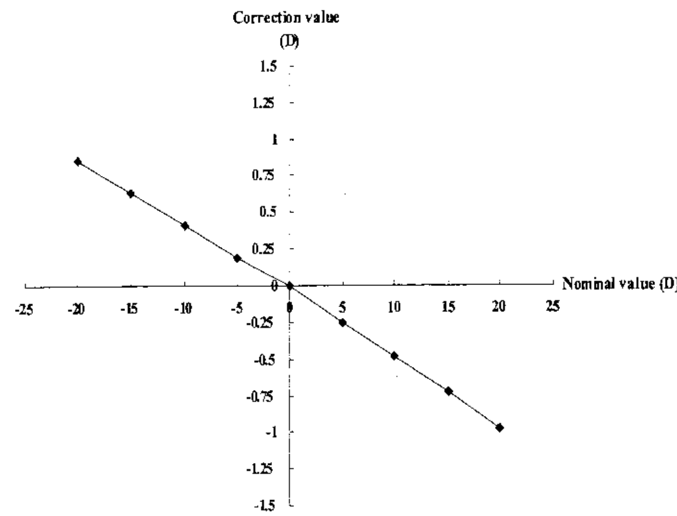

FIGURE 4.
Correction values on spherical aberration.

Characteristic Errors from Different Focimeters

There are many differences in mechanical and optical design among the different models of manual focusing focimeters, which we call "characteristic errors." These include the scale error, the size error from the lens support, and other uncertain factors. Also, an effect of nonlinear correction is very evident in both the electronics of digital reading of the focimeters and the mechanics of the eyepiece type of focimeters.

As one can see from Table 2 and Fig. 1a, the correction values A with the NIM special test lenses measured by four focimeters (including two LM-P6 models, one LM-380, and one LM-8) show asymmetric error effects between the positive and negative power ranges. But the correction values A for LM-770 and two QY-III models show symmetry in this respect. From Table 2 and Fig. 1b, we find that the correction values B from using the conventional lens series (test lenses conforming to ISO 9342) measured with the seven focimeters are very small.

Therefore, if a focimeter, with either electronic or mechanical display, is calibrated with test lenses conforming to ISO 9342, it can be used only for spectacle lens measurement, and the performance is very good, as shown by the correction value B in Table 2 and Fig. 1b. But one cannot get the same good performance when measuring contact lenses with the focimeter calibrated in this fashion.

Although an electronic or mechanical correction (perhaps nonlinear) on the focimeters can reduce correction values for spectacle lens measurement on the basis of metrological calibration, it can at

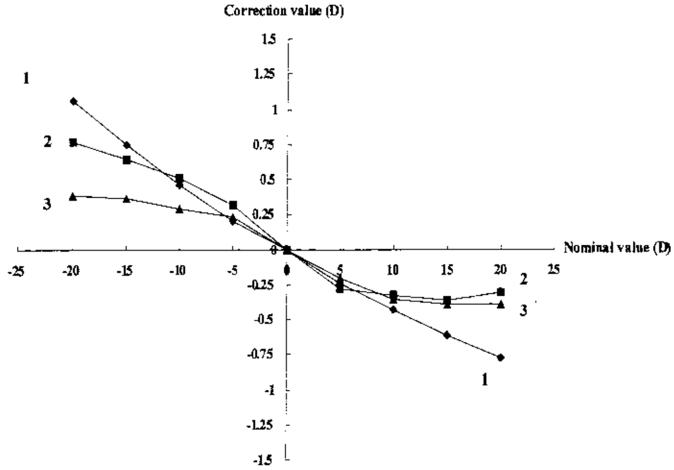

FIGURE 5.
Comparison between measuring correction values and theoretical calculations. Curve 1, theoretical calculation; curve 2, correction values of LM-P6 (correction A in Table 2), No. 816610; curve 3, correction values of LM-770 (correction A in Table 2), No. 23359.

the same time leave an asymmetric error effect in contact lenses measurement, as shown by the correction value A in Table 2 and Fig. 1a. These unexpected effects could only come from the focimeters themselves because the same special test lenses were used in all focimeters but only certain models showed asymmetrical effects. To solve the effect of asymmetry and get correction values as good as spectacles, a set of standardized special lenses should be used to calibrate focimeters when used for the measurement of contact lenses.

Standardization and Uniformity for Contact Lens Measurement

The characteristic error from different focimeters raised another important question of standardization and uniformity for contact lenses. Obviously, we cannot be satisfied with such a big difference, induced by both an inadequate calibration method conforming to ISO 9337-1 and the characteristic errors from different focimeters on the measurement of back vertex power for contact lenses because they are a special product being used to correct the defects of human vision. Therefore, we have to take into consideration both the calibration method of focimeters and the standardization and uniformity of contact lenses measurement worldwide.

Applicability of the NIM Special Test Lenses

Due to the existence of different structural parameters between the NIM special test lenses and the contact lenses sold in market, the NIM group carried out another theoretical analysis on the influence of several factors, such as refractive index, central thickness, back surface radius of curvature, and so on, to verify its applicability. The results are given below.

Calculation of Refractive Index and Central Thickness

The material used in rigid contact lenses is diverse, and the refractive indexes range from 1.41 to 1.49. Also, the central thickness of contact lenses sold in market is different from that of the NIM special test lenses in that the special test lenses are thicker. For reasons of stability, the NIM special test lenses are made of optical glass and with sufficient central thickness for precision manufacture. It is a well-known fact that neither the index of refraction nor the central thickness of the test lenses will influence the action of a focimeter. Nevertheless, we did a calculation from refractive index and central thickness. The results verified that neither the index of refraction nor the central thickness of the test lenses affected the action of a focimeter.

Calculation of the Influence of Back Surface Radius of Curvature

To consider the influence of different back surface radii of curvature on measurement results, which are induced by spherical aberration, we calculated the back vertex power on the back surface radii of 7 mm, 8 mm, and 9 mm, respectively (7.942 mm is the back surface radius of the NIM lenses). Then we calculated the vertex power deviations from the back surface radii 7 mm and 8 mm as well as the back surface radii 8 mm and 9 mm. The results show that the biggest deviation occurs at ±20 D; it is about 0.27 D (Fig. 6).

CONCLUSION

Based on the above experiments and calculations, one can conclude the following:

1. When focimeters are calibrated to find correction values with the method specified in ISO 9337-1, measurement error will not be eliminated if these correction values are used in measuring contact lenses, and the resulting deviation is too large to be ignored.
2. Therefore, the correction values obtained by calibrating focimeters with conventional test lenses as specified in ISO 9342 should not be used directly in contact lens measurement as described in ISO 9337-1.
3. It is important to realize the standardization and uniformity of

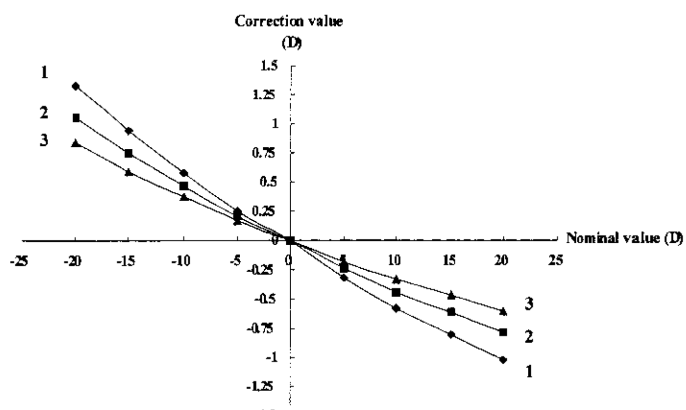

FIGURE 6.
Differences among the correction values derived from different back surface radius of curvatures. Curve 1, correction values of 7-mm back surface radius of curvature; curve 2, correction values of 8-mm back surface radius of curvature; curve 3, correction values of 9-mm back surface radius of curvature.

contact lens measurements worldwide because contact lenses are a special product being used to correct human vision.

4. Special test lenses should be used to calibrate focimeters to find correction values when these focimeters are used to measure the back vertex power of contact lenses.

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Li Ru Wang
Optical Engineering Division
National Institute of Metrology
HePing Street, 100013
Beijing, CHINA
e-mail: star@public.bta.net.cn