Accuracy of WASCA Aberrometer Refraction Compared to Manifest Refraction in Chinese Adult Myopes

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ABSTRACT

PURPOSE: To investigate the accuracy of the Carl Zeiss Meditec Wavefront Supported Custom Ablation (WASCA) aberrometer in refraction testing for Chinese myopic adults.

METHODS: Manifest refraction and WASCA were performed on 360 eyes of 360 consecutive Chinese myopic adults without cycloplegia. Both vector analysis and conventional notation were applied for comparing results, and differences between WASCA and manifest refraction for each component were calculated for accuracy evaluation. Correlation coefficients, regression equations, and mean errors of each component between the two methods were also tested.

RESULTS: Pearson correlation coefficient for M, J_0, J_{45}, sphere, and cylinder was 0.9680, 0.9320, 0.8655, 0.9668, and 0.8761, respectively. Mean error for the components above was -0.39 ± 0.71 diopters (D), -0.02 ± 0.16 D, 0.01 ± 0.12 D, -0.42 ± 0.70 D, and 0.06 ± 0.30 D, respectively. In patients whose manifest vector M was $\leqslant-6.00$ D, mean errors of sphere and vector M were larger than the remainder of the study group. Ninety percent cylinder errors were within ±0.50 D. Mean error of axis was 7.4°, with 50% of eyes within 5°. In cases with $\leqslant-0.75$ D astigmatism, mean error of axis was 9.8°, which was larger than the remainder of the study group by 4.9°.

CONCLUSIONS: For Chinese myopic adults, the concordance between WASCA and manifest refraction is, on average, high. However, for eyes with low to moderate spherocylindrical refraction, WASCA is less accurate in predicting sphere and vector M. It is also less effective for the measurement of axis in patients with astigmatism <0.75 D. [*J Refract Surg*. 2009;25:1026-1033.]

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Currently, a variety of aberrometers, providing measurements of lower order aberrations as well as higher order aberrations, have been widely used to measure monochromatic aberrations of the human eye in pre- and postoperative examinations for refractive surgery.[1-3] One of these instruments, the Wavefront Supported Custom Ablation (WASCA) aberrometer (Carl Zeiss Meditec AG, Jena, Germany), which works in accordance with the Hartmann-Shack principle, is preferred in clinical examinations. Thus, understanding the accuracy of the WASCA system becomes important. Salmon et al[4] tested the accuracy and repeatability of the Complete Ophthalmic Analysis System (COAS; WaveFront Sciences, Albuquerque, NM), which is the same model as the WASCA used in the United States. By comparing the refraction (spherical error and astigmatism) obtained from the COAS with that from an autorefractor and conventional subjective refraction for 20 patients, they found similar performances among the three different measurements. Reinstein et al[5] assessed the accuracy of cycloplegic WASCA refraction by a single measurement in 50 eyes of 25 myopic patients and also found that the concordance between manifest and WASCA refractions was, on average, high in normal myopic eyes.

However, most patients in the previous two studies had low to intermediate myopia, with only a few having high myopia, and the sample sizes were also small.[4] To accurately measure refraction for high myopia, a system needs high accuracy within a large range. In China, the prevalence of myopia is very high and consequently the prevalence of high myopia is high as well. It is therefore clinically important

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to understand the accuracy of the WASCA system in examining high myopia.

In this study, we measured refractions for 360 Chinese myopic young adults with equivalent refractive errors ranging from −0.25 to −15.25 diopters (D) using the WASCA system and the clinical subjective refraction test and compared the accuracy between the two measurement methods. The results of our study indicate that the accuracy of WASCA refraction varies with different degrees of myopia, and the level of astigmatism also affects WASCA measurement of axis.

PATIENTS AND METHODS

This retrospective study included 360 consecutive Chinese myopic patients who were suitable for LASIK or laser epithelial keratomileusis at our institution from September 2005 to June 2007. All patients were mentally healthy, and those wearing contact lenses had discontinued wear for at least 2 weeks prior to examination. Patients with other ocular pathologies were excluded from the study.

EXAMINATIONS

Routine preoperative examination included visual acuity, tonometry, slit-lamp microscopy, tear breakup time test, funduscopy, corneal topography, and pachymetry. Retinoscopy was carried out according to the results of autorefraction with the ARK-700A autorefractor (NIDEK Co Ltd, Gamagori, Japan). All manifest refractions (Manifest_Sphere, Manifest_Cylinder, and Manifest_Axis) were then performed by an optometrist using the RT-2100 automated refractor (NIDEK Co Ltd) in a standard illuminated environment following the standard protocol below: 1) monocular refraction to achieve maximum plus to maximum visual acuity, 2) monocular duochrome test, 3) refinement of the cylinder axis and power, 4) monocular refraction to achieve maximum plus to maximum visual acuity a second time, using the duochrome test to verify the endpoint, 5) binocular balance, and 6) binocular maximum plus to maximum visual acuity. Only data obtained on the day of surgery were considered as the best estimates of manifest refractions for this study.

After manifest refractions were performed, WASCA aberrometry without cycloplegia was obtained. During the process, the patient was adjusted in a dark room and required to position his/her head on a chin rest and fixate the center of a circular grid, which was optically fogged by approximately 1.50 D. Aberrometry measurements were taken by the operator until the criteria described by Reinstein et al[5] were met.

In all cases, the scotopic pupil diameter was larger than the analyzed pupil size that was set at 5.5 mm for determining Zernike coefficients. We also used the "Seidel sphere" option within the WASCA system,[4] which included primary spherical aberration in the computation of sphere power and improved the fit of the wavefront to a sphere for large pupils. Second order aberrations consisting of spherical and cylindrical components were recorded (WASCA_Sphere, WASCA_Cylinder, and WASCA_Axis).

As there were correlations between the two eyes of a patient, only data of right eyes were recorded for this study. All spheres and cylinders were recorded in minus form.

STATISTICAL ANALYSIS

Statistical analyses were performed using the SPSS program version 13 (SPSS Inc, Chicago, Ill). For vector analysis, each measurement was converted to a power vector with the form M (sphere+cylinder/2) (WASCA_M and Manifest_M), J_0 ([cylinder/2]cos[2*axis]) (WASCA_J_0 and Manifest_J_0), and J_{45} ([cylinder/2]sin[2*axis]) (WASCA_J_{45} and Manifest_J_{45}) as described by Thibos and Horner.[6] Each was a geometrical representation of spherocylindrical refractive errors and mathematically independent of the others. For conventional measurements, we made direct comparisons of sphere, cylinder, and axis, respectively. We calculated the mean, standard deviation, standard error, and 95% confidence interval (95% CI) of the mean for each vector component, sphere, and cylinder. Linear regression analysis was performed to confirm correlations between the two methods for these components.

Accuracy was defined as the difference between WASCA and manifest refraction for each component (E_M, E_J_0, E_J_{45}, E_S, and E_C). The absolute dioptric error was calculated as defined by Thibos and Horner.[6] For the axis, although the difference of axis between WASCA and manifest refraction was also calculated, we used the absolute value of this difference as its error (E_A).

Statistics were performed on the error of each component, using paired *t* tests at the 5% level. Further comparisons of mean errors of vector M as well as sphere were made between patients with Manifest_M ≤ -6.00 D and those with Manifest_M > -6.00 D using independent sample *t* test. Distributions of E_C, E_A, and difference of axis between WASCA and manifest refraction were also presented. Comparisons of mean value of E_A were made between the patients with cylinder ≤ -0.75 D and those with cylinder > -0.75 D using independent sample *t* test as well.

RESULTS

The study population comprised 360 patients (215 women, 145 men) with a mean age of 27.6 years (range:

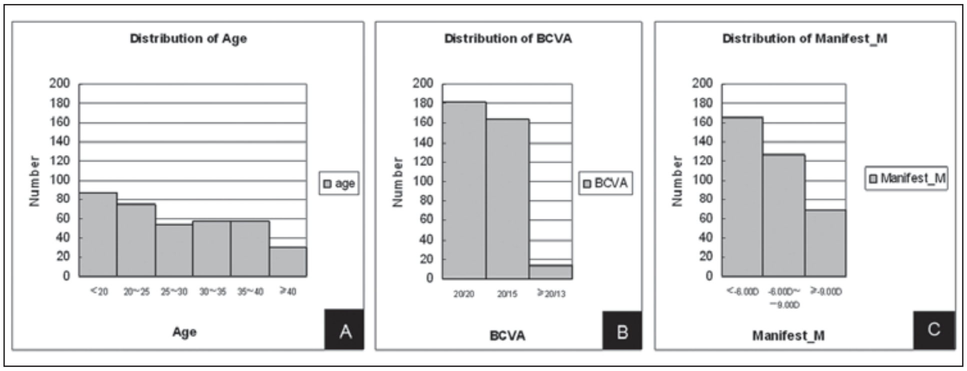

Figure 1. Histograms for the distribution of **A)** age, **B)** best spectacle-corrected visual acuity (BCVA), **C)** and Manifest_M.

TABLE 1

Descriptive Statistics for Each Component for 360 Eyes That Underwent Manifest Refraction and WASCA Aberrometry

Component	Mean	Standard Deviation	Standard Error	95% Confidence Interval
WASCA_M	−6.90	2.57	0.14	(−6.63, −7.17)
Manifest_M	−6.51	2.78	0.15	(−6.22, −6.80)
WASCA_J_0	0.28	0.42	0.02	(0.24, 0.32)
Manifest_J_0	0.30	0.44	0.02	(0.26, 0.35)
WASCA_J_{45}	0.05	0.21	0.01	(0.02, 0.07)
Manifest_J_{45}	0.03	0.23	0.01	(0.01, 0.06)
WASCA_Absolute dioptric error	6.92	2.57	0.14	(6.66, 7.19)
Manifest_Absolute dioptric error	6.54	2.78	0.15	(6.25, 6.83)
WASCA_Sphere	−6.44	2.52	0.13	(−6.18, −6.70)
Manifest_Sphere	−6.02	2.71	0.14	(−5.74, −6.30)
WASCA_Cylinder	−0.92	0.60	0.03	(−0.86, −0.98)
Manifest_Cylinder	−0.98	0.61	0.03	(−0.92, −1.05)

M = refraction, J_0 = cylindrical power at 0°, J_{45} = cylindrical power at 45°

18 to 57 years). All patients had best spectacle-corrected visual acuity (BSCVA) of 20/20 or better. Mean sphere was −6.02±2.71 D (range: −0.25 to −15.25 D). Mean cylinder was −0.98±0.61 D (range: −0.25 to −3.75 D). Figure 1 shows the distribution of age, BSCVA, and Manifest_M.

Table 1 shows the descriptive statistics of the vector components, sphere, and cylinder of the study group.

Pearson correlation coefficients for the M, J_0, and J_{45} vector components were 0.9680, 0.9320, and 0.8655, respectively (all $P<.0001$). The values for sphere and cylinder were 0.9668 and 0.8761 (both $P<.0001$). Figure 2 shows scatterplots comparing each component between WASCA and manifest refractions. The regression equations for M, J_0, J_{45}, sphere, and cylinder showed that the slope was close to 1 in all cases: 0.8947, 0.9016, 0.7860, 0.9013, and 0.8545, respectively. The intercept was −1.0753, 0.0064, 0.0206, −1.0153, and −0.0811, respectively.

Table 2 shows the statistics for each error component. None of the 95% CIs of the mean for the three error vector components included zero. Univariate paired *t* tests indicated that E_M, E_J_0, and E_J_{45} were significantly different from zero. The results suggested that systematic errors in refraction exist between the two methods for a large sample. The mean absolute dioptric error between the two methods was 0.65 D, with 48.3% of eyes within 0.50 D and 81.9% within 1.00 D. Likewise, for E_S, E_C, and E_A, none of the 95% CIs of the mean included zero, and univariate paired *t* tests also indicated that they were significantly different from zero.

Table 3 displays the distribution of E_C. Sixty-five percent of the E_C were within ±0.25 D and 90% within ±0.50 D. The total error range of cylinder was between −0.85 and 1.25 D.

Table 4 displays the distribution of absolute values of difference of cylinder axis between the two methods (E_A). Half of the E_A were within 5°, 75.3% within 10°, and 88.3% within 15°.

Table 5 displays the distribution of difference of axis between WASCA and manifest refraction. There were 43.6% patients whose E_A was >5°, among which 59.9% had WASCA_Axis located in a counterclockwise direction from Manifest_Axis.

Analysis of Subgroups

Low to Moderate Myopia Group and High Myopia Group. Figure 3 shows the descriptive statistics for each component in the low to moderate myopia group (Manifest_M ≤−6.00 D) and high myopia group (Manifest_M >−6.00 D).

For the low to moderate myopia group, Pearson correlation coefficients for M, J_0, J_{45}, sphere, and cylinder were 0.9003, 0.9226, 0.8539, 0.8976, and 0.8252, respectively (all $P<.0001$). For the high myopia group, Pearson correlation coefficients for M, J_0, J_{45}, sphere, and cylinder were 0.9281, 0.9349, 0.8736, 0.9285, and 0.8987, respectively (all $P<.0001$).

Figure 4 shows the statistics for each error component in the subgroups (Manifest_M ≤−6.00 D, ≤−9.00 D, and >−9.00 D). The mean E_M was −0.59±0.57 D within 173 patients in the low to moderate myopia group, which was larger than the value of −0.20±0.77 D in the 187 patients in the high myopia group by −0.39 D (t=5.3662, $P<.0001$). Likewise, the mean E_S was −0.61±0.59 D for the low to moderate myopia group, which was larger than the value of −0.25±0.75 D for the high myopia group by −0.36 D (t=5.0235, $P<.0001$). Notably, in the Manifest_M >−9.00 D group, the mean E_M and E_S were 0.12 D and 0.05 D, respectively, both of which were not statistically different from zero (t=1.1764, $P=.2439$; t=0.5104, $P=.6116$, respectively).

Astigmatism and Axis. As we analyzed the cylinder magnitudes of the 89 patients whose E_A was ≥10°, we found a mean value of −0.73±0.43 D, which was lower than the value of −1.07±0.64 D for patients whose E_A was <10° (t=−4.6617, $P<.0001$). However, the differences of sphere and age between them were not statistically significant (t=−0.9148, $P=.3609$; t=0.0712, $P=.9432$, respectively). Thus, we further studied the 188 cases whose cylinder was ≤−0.75 D. Interestingly, we found that their mean E_A was 9.8° (95% CI: 8.0, 11.5), which was larger than the value of 4.9° (95% CI: 4.2, 5.6) for the remaining 172 cases, whose cylinder was >−0.75 D, by approximately 5° (t=4.9050, $P<.0001$).

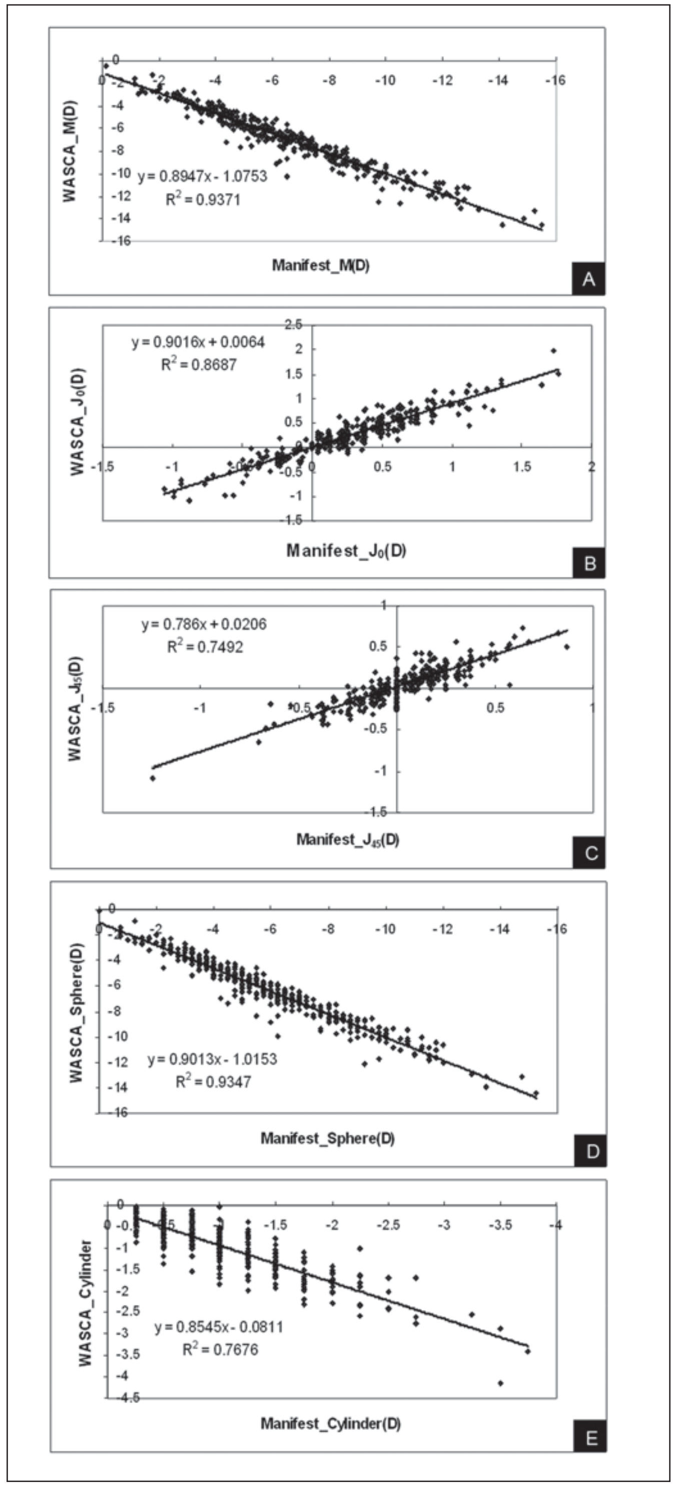

Figure 2. Scatterplots of WASCA refraction versus manifest refraction. An individual plot with the regression equation for each vector component is presented. **A)** M, **B)** J_0, **C)** J_{45}, **D)** sphere, and **E)** cylinder.

DISCUSSION

In this study, the accuracy of WASCA refraction in Chinese adults with myopia is, on average, high. However, exceptions exist and accuracy for each component is analyzed below.

TABLE 2

Statistics for Each Error Component for 360 Eyes That Underwent Manifest Refraction and WASCA Aberrometry

Component	Mean±Standard Deviation	95% Confidence Interval	*P* Value	Range
E_M	−0.39±0.71	(−0.46, −0.32)	<.0001	−3.74 to 1.95
E_J_0	0.02±0.16	(−0.04, −0.01)	.0052	−0.68 to 0.44
E_J_{45}	0.01±0.12	(0.00, 0.03)	.0273	−0.53 to 0.45
Absolute dioptric error	0.65±0.52	(0.09, 2.07)		0.02 to 3.74
E_S	−0.42±0.70	(−0.49,−0.35)	<.0001	−3.70 to 1.62
E_C	0.06±0.30	(0.03,0.09)	.0001	−0.85 to 1.25
E_A*	7.4±9.7	(6.4, 8.4)	<.0001	0 to 81

E = error, M = refraction, J_0 = cylindrical power at 0°, J_{45} = cylindrical power at 45°, S = sphere, C = cylinder, A = axis
*Unit of measure is degrees.

TABLE 3

Distribution of E_C for 360 Eyes That Underwent Manifest Refraction and WASCA Aberrometry

No. Eyes (%)					
E_C (D)					
<0.50	**−0.50 ~ −0.25**	**−0.25 ~ 0.25**	**0.25 ~ 0.50**	**>0.50**	**Total**
10 (2.8)	31 (8.6)	234 (65)	59 (16.4)	26 (7.2)	360 (100)

E_C = error of cylinder

TABLE 4

Distribution of E_A for 360 Eyes That Underwent Manifest Refraction and WASCA Aberrometry

No. Eyes (%)				
E_A (°)				
<5	**5 ~ 10**	**10 ~ 15**	**>15**	**Total**
180 (50)	91 (25.3)	47 (13)	42 (11.7)	360 (100)

E_A = error of axis

TABLE 5

Distribution of Difference of Axis Between WASCA and Manifest Refraction

No. Eyes (%)						
Axis (°)						
<−15	**−15≤Axis<−5**	**−5≤Axis<0**	**0**	**0<Axis≤5**	**5<Axis≤15**	**>15**
12 (3.3)	51 (14.2)	91 (25.3)	24 (6.7)	88 (24.4)	67 (18.6)	27 (7.5)

Axis = difference of axis
Note. In right eyes, if Axis is <0, WASCA_Axis locates in a clockwise direction from Manifest_Axis and vice versa.

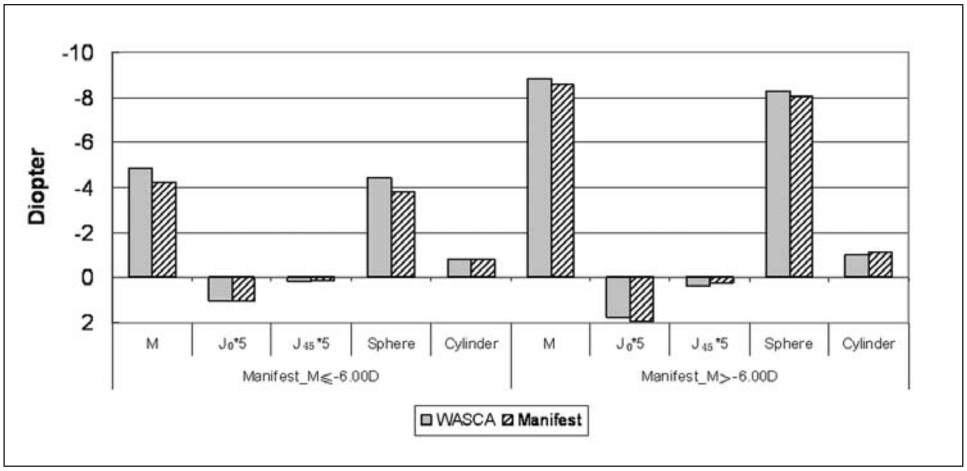

Figure 3. Descriptive statistics for each vector component, sphere, and cylinder in the low to moderate myopia group (Manifest_M ≤6.00 D) and high myopia group (Manifest_M >6.00 D).

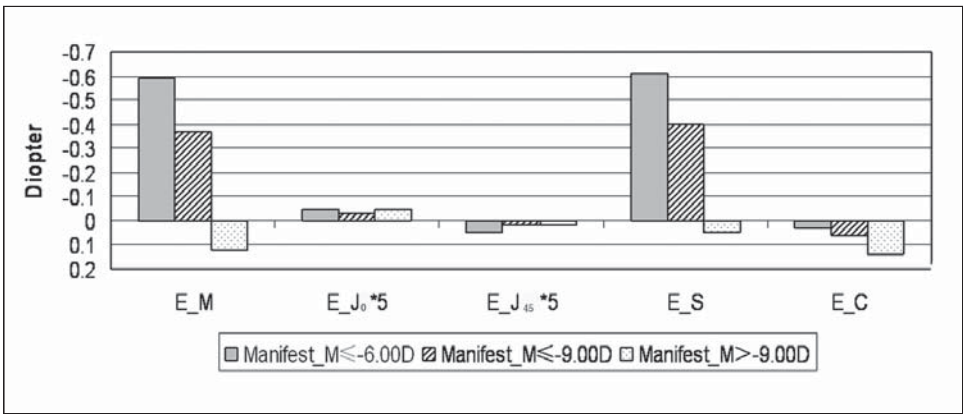

Figure 4. Statistics for each error component in subgroups Manifest_M ≤−6.00 D, ≤−9.00 D, and >−9.00 D.

Comparison of Vector M and Sphere

General Analysis. For vector M, the mean error is −0.39 D, which means, without cycloplegia, WASCA measures slightly more myopia than manifest refraction. However, the statistical analysis of sphere and cylinder implies that E_M is mainly affected by E_S. Several factors can account for this.

First, the endpoint of manifest refraction is to achieve maximum plus to maximum visual acuity (ie, the minimum minus in myopia), which will systematically make the results of manifest refraction less myopic than those of WASCA. Second, manifest refraction is performed under natural light, for which reference wavelength is based on theoretical and experimental evidence of 570 nm, whereas WASCA refracts with 850 nm infrared light and then mathematically corrects this for a default value of 550 nm. The chromatic aberration between 550 and 570 nm will cause an approximate −0.10 D error of the result.[7] Because WASCA measured on average more myopia than manifest refraction in this study, it is possible that the current default value is slightly overcorrected, and 570 nm might be a better choice for the built-in correction of WASCA. In addition, instrument myopia, which occurs when the patient is viewing the instrument's internal fixation target that is optically projected to infinity, might be another reason for this error as described by Cervino et al.[8] Finally, as the computation of sphere power within the WASCA includes primary spherical aberration, the influence of pupil size is not negligible. Although we did not measure pupil size during manifest refraction, we realize that it is conducted in a relatively better illuminated environment than WASCA refraction. Therefore, the pupil size is relatively larger during WASCA refraction, which would bring about greater higher order aberrations, especially spherical aberration, and less depth of focus. As Buehren et al[9] reported that the levels of higher order aberrations within the range of 0.2 to 0.3 μm for a 5-mm pupil diameter would induce clinically significant spherocylindrical change (ie, ≥0.25 D), the increased higher order aberrations would also affect the results of WASCA refraction in this study.

Notably, the mean absolute dioptric error between the two methods is 0.65 D, which is slightly higher than the value of 0.43 D presented by Reinstein et al.[5] Because manifest refraction was carried out strictly in accordance with the standard protocol, we believe the main cause of the disparity between the two studies lies within WASCA refraction, which was carried out without cycloplegia in this study. Although the eyes were optically fogged by approximately 1.50 D during aberrometry, this would not necessarily eliminate as much accommodation as cycloplegia in all patients, which leads to the relatively high absolute dioptric error in this study.

The 95% CI of E_M is between −0.46 and −0.32 D, and the Pearson correlation coefficients for vector M and sphere are as high as 0.9680 and 0.9668, respectively. These results are generally consistent with that of Salmon et al[4] who also found that accuracy of COAS was satisfactory without cycloplegia.

In addition, as for the few cases whose absolute value of E_S is >1.00 D, differences in patient cooperation during the two examinations might also be a factor.

Characteristics of Different Degrees of Myopia. Study of E_M and E_S shows that WASCA is less accurate in predicting vector M and sphere for eyes with low to moderate spherocylindrical refraction. This noncycloplegic study is also in agreement with the cycloplegic study of Mirshahi et al[10] who tested the Zywave aberrometer (Bausch & Lomb, Rochester, NY), which works on the same principle as WASCA, and found that it was less accurate for eyes with a similar refractive state. This similarity of results under two different accommodation states suggests that this inaccuracy for eyes with small spherocylindrical refraction might be a common phenomenon in the Hartmann-Shack devices.

For high myopia, the WASCA aberrometer works with better accuracy. The mean error of vector M is within 0.25 D and Pearson correlation coefficients for each component are higher than those of low to moderate myopia. Moreover, as seen in Figure 4, the mean E_M and E_S also present a tendency to decrease with increasing myopia. In the Manifest_M >−9.00 D group, the mean E_M and E_S are not statistically different from zero, alluding to the fact that WASCA is not only useful for predicting vector M and sphere for high myopia, but also favorable for extreme myopia.

As the "Seidel sphere" option includes primary spherical aberration, which is more common in high myopia, in the computation of sphere power, it may contribute to the differences of WASCA accuracy between low and high refractive errors. For those patients with low to moderate myopia, Cheng et al[11] have shown that root-mean-square wavefront error might be a good predictor.

Comparisons of Vector J_0, J_{45}, and Cylinder

Concordances of vector J_0 and J_{45} between WASCA and manifest refraction are, on average, high, in that their mean errors are both within ±0.25 D and 95% CIs of their errors are both as narrow as 0.03 D. Reinstein et al[5] performed a similar study to ours, and found WASCA was accurate in predicting these two vector components. Besides, E_J_0 and E_J_{45} are not statistically different between the low to moderate group and high myopia group, suggesting the accuracy of WASCA cylinder measurement may not change with degree of myopia.

From Table 3, approximately 10% of patients have an absolute value of the E_C >0.50 D; however, because the mean of E_C is 0.06 D and the 95% CI of E_C for the population is within the range of 0.03 to 0.09 D, it could be predicated that WASCA refraction is accurate in most cases in predicting the magnitude of cylinder.

Analysis of Axis Measurement

Although direct comparisons of sphere, cylinder, and axis might be considered as inadequate to test statistical relationships between multiple measurements, they could be used for quick judgments on the accuracy of WASCA refraction in clinical work, as calculations of vectors may be time-consuming for clinicians.

Absolute value of axis difference between the two methods as a token of E_A was calculated and the results show that half of this sample's E_A are >5°. For those with large E_A, their astigmatism is found to be on average low. Interestingly, the mean E_A is 9.8° in those with ≤−0.75 D astigmatism, which is larger than the value of 4.9° for the remaining patients by 4.9°. This also coincides with the data of Mirshahi et al.[10] Our study suggests that −0.75 D might be viewed as a useful cutoff point for quick judgment on accuracy of WASCA axis measurement in clinical work.

As to other possible reasons why the concordance between WASCA and manifest refraction is not as high for the measurement of axis as for other components, aside from the above-mentioned possible properties of the Hartmann-Shack devices, cyclotorsion of the eye comes to mind, which is a phenomenon that usually occurs when the position of the patient is changed. A previous study conducted by Ciccio et al[12] on 1019 eyes of 732 patients found that the main trend of the eye was for excyclotorsion when the patient changed his/her position from the seated to supine. They also found that the total range of cyclotorsion was 0.5° to 17.5°, with an average of 4.05°.

Although both the WASCA refraction and manifest refraction were taken in the seated position, the accommodation state was different between the two processes in this study. Because WASCA without cycloplegia measures slightly more myopia than the manifest refraction, we propose a hypothesis that this difference somehow results in the cyclotorsion that occurred during the two processes, which partly eliminates the accuracy of WASCA in the measurement of axis.

From Table 5, more patients with E_A >5° have the WASCA_Axis located in a counterclockwise direction from Manifest_Axis. If this is not all caused by the device itself, it seems that accommodation might cause slightly more excyclotorsion than incyclotorsion in right eyes according to our hypothesis. However, as the relationship between accommodation and cyclotorsion remains illusive, further studies are necessary.

In the current study, we conclude that accuracy of WASCA aberrometer refraction in Chinese adults with myopia is generally good, especially for high myopia. It is less effective for the measurement of axis in patients with low astigmatism.

AUTHOR CONTRIBUTIONS

Study concept and design (X. Zhu, J.D., R.C.); data collection (X. Zhu, L.W.); interpretation and analysis of data (X. Zhu, Y.L., X. Zhou); drafting of the manuscript (X. Zhu); critical revision of the manuscript (J.D., R.C., Y.L., X. Zhou, L.W.); administrative, technical, or material support (Y.L., X. Zhou)

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