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Accuracy of WASCA Aberrometer Refraction Compared to Manifest Refraction and Cycloplegic Refraction in Hyperopia Measurement

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Purpose: To explore the agreement between the wavefront supported custom ablation (WASCA) aberrometer and manifest refraction (MR) and cycloplegic refraction (CR) in hyperopia testing.

Methods: Ninety eyes of 90 hyperopic patients (spherical equivalent $\geq +0.5$ D) were evaluated; MR, CR, and WASCA refraction (WR) were performed consecutively. Analysis pupil size was 6.0 mm in WASCA measurement using the Seidel method. The conventional notation was transferred into vector components for analysis, i.e., spherical equivalent (M) and two cross-cylinders at axis 0° (J_0) and axis 45° (J_{45}). Bland-Altman plots were used to test the agreement between the two measurements.

Results: The mean Ms obtained with MR and CR were 3.23 $\pm$ 1.74 D and 4.04 $\pm$ 2.04 D, respectively ($P < 0.001$), and the correlation was high ($r = 0.90$, $P < 0.001$). The WR was highly correlated with MR and CR in terms of M ($r = 0.89, 0.87$), but not significantly correlated in J_0 and J_{45}. The total dioptric power vector error was 0.18 $\pm$ 1.00 D between WR and MR and -0.64 ± 1.03 D between WR and CR. The limits of agreement of all vector components were beyond $\pm$ 1.0 D. With hyperopia level increase, WR tended to overestimate MR ($P = 0.04$), whereas WR always underestimated CR.

Conclusions: WASCA could act as a reference of subjective refraction in hyperopia measurement, the exchangeability is not fully applicable.

Translational Relevance: WASCA can provide an alternative for objective refraction in hyperopia measurement.

Introduction

With the increase in refractive surgery, preoperative refraction testing is an essential step for a successful operation. Hyperopia, accounting for a relatively small proportion of surgical cases in Asian countries,[1] is a clinical challenge for optometrists because of high accommodation.[2] The wavefront aberrometer has been widely used to measure ocular aberrations, including lower-order spherical error and astigmatism.[3] Thus wavefront supported custom ablation (WASCA) provides an alternative for refraction testing and for the assessment of the accuracy of refractive surgery.[4]

Our team previously reported high agreement between WASCA and manifest refraction (MR) in the myopic population.[5] Some studies also focused on myopic, cataract, or post-LASIK refraction measurements.[4,6,7] However, research on the measurement of hyperopia is limited. This study aimed to determine the agreement of WASCA and MR, as well as cycloplegic refraction (CR) in patients with hyperopia.

Patients and Methods

This study was performed at the Eye and ENT Hospital of Fudan University. Refractive data were

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collected from the surgical database; approval from the appropriate Ethics Committee was obtained (No. KJ2008-10). All patients were asked to sign an informed consent form before the refractive surgery. All examinations adhered to the tenets of the Declaration of Helsinki.

Our study included subjects with a minimum age of 18 years, sphere equivalent $\geq +0.5$ D, and best-corrected visual acuity $\geq$ 20/25. The included patients had not worn soft contact lenses for at least one week before surgery or rigid lenses for four weeks. The exclusion criteria were ocular surgical history, other eye diseases except for hyperopia, and unwillingness to undergo subjective refraction. All right eyes were intended to be enrolled. When the right eye did not adhere to the inclusion criteria, the other eye would be enrolled.

All patients received regular preoperative examinations (subjective refraction, corneal topography, intraocular pressure, and fundus examinations). MR, including manifest sphere, manifest cylinder, and manifest axis, was performed using a phoropter (RT-2100; Nidek Co Ltd, San Jose, CA, USA). Best-corrected visual acuity was recorded using the standard projected Snellen acuity chart with four optotypes per line. The vertex distance remained 12 mm during all procedures. The protocol of refraction was the same as that described by Zhu et al.[5] All refraction tests were completed by a trained, experienced optometrist under the same illumination.

CR was performed after administration of Tropicamide Phenylephrine eye drops at 10-minute intervals. Negative light reflection was regarded as a successful indicator of maximized accommodation weakened. Then, the WASCA analyzer (Carl Zeiss Meditec, Oberkochen, Germany) using the Shack–Hartmann wavefront sensor was used, which consists of an array of microlenses arranged in front of a video camera (or CCD). Each examination was performed by the same observer in a dark room. We selected 6.0 mm as the analysis diameter, which was lower than all scotopic diameters. Using "Seidel sphere" mode,[8] the computed refraction (WR: W-S, W-C, W-A, respectively, stand for sphere, cylinder, and axis) incorporated primary spherical aberration in addition to lower-order aberration. According to the manufacturer's recommendation, the accepted image quality was as follows: a largely centered wavefront inside the window and not clipped at the window edges, except for one or two pixels usually near the center (cornea reflection), and the pattern showing a completely filled data pixel structure.

Subgroups were divided by the spherical equivalent (SE) of MR, in a low hyperopia group (SE $\leq$ 2.0 D), moderate hyperopia group (2.0 D $<$ SE $\leq$ 4.0 D), and high hyperopia group (4.0 D $<$ SE).

Statistics

Power vector transformation was performed before the analysis.[9] That is, astigmatism was converted to Fourier form: two cross-cylinders at axis 0° (J_0) and axis 45° (J_{45}). All refraction results were converted to the power vector in the form of J_0, J_{45}, and M, which are independent power profiles describing spherocylindrical parameters. The length of this vector is a measurement of the overall blurring strength of a refractive error (described as B later in the text).

Linear regression was used to analyze the correlation among WR, MR, and CR. Paired *t*-test were used to describe the difference (error, E) between two methods (Ew-c = WR-CR, Ew-m = WR-MR). Bland-Altman plots were constructed to visualize the agreement between the two methods. Bland-Altman plots are scatter graphs of the differences (error as described above) between two measurements against the average of the two. These were plotted showing a horizontal line delineating the mean error and two further lines delineating the limits of agreement (LoAs).

Results

Correlation Analysis

Ninety eyes from 90 patients, with an average age of 32.1 $\pm$ 11.8 years, were included. The best-corrected visual acuity was cumulatively at least 20/15 in 15.6% of eyes, 20/20 in 65.6% of eyes, and 20/25 in all eyes. The specific data of conventional MR, CR, and WR, with their vector components are shown in Table 1. The sphere in CR was 0.85 $\pm$ 0.91 D higher than that in MR, and the correlation coefficient was 0.90 ($P < 0.001$). No difference was found in cylinder between CR and MR ($P > 0.05$).

The linear regression results are shown in Table 2. Figure 1 shows scatterplots comparing each parameter of these two methods. Pearson's correlation coefficients for M, J_0, and J_{45} between WR and MR were 0.89 ($P < 0.001$), -0.08 ($P = 0.44$), and -0.27 ($P = 0.01$), respectively. The correlation coefficients for M, J_0, and J_{45} between WR and CR were 0.87 ($P < 0.001$), -0.07 ($P = 0.54$), and -0.02 ($P = 0.84$), respectively.

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Table 1. Descriptive Statistics for WASCA, Manifest Refraction and Cycloplegic Refraction Values (Mean ± SD)

	Sphere (D)	Cylinder (D)	Axis	M (D)	J_0 (D)	J_{45} (D)	B (D)
MR	3.72 ± 1.79	−0.99 ± 0.86	102 ± 63	3.23 ± 1.74	−0.08 ± 0.43	0.08 ± 0.48	3.32 ± 1.70
CR	4.58 ± 2.05	−1.00 ± 0.86	102 ± 64	4.04 ± 2.04	−0.08 ± 0.45	−0.04 ± 0.46	4.11 ± 2.01
WR	3.91 ± 2.31	−1.12 ± 0.90	86 ± 62	3.35 ± 2.27	0.00 ± 0.56	−0.01 ± 0.45	3.50 ± 2.19

WR, WASCA refraction; M, spherical equivalent; B, overall blurring strength of a vector refraction; D, diopter.

Table 2. Linear Regression Analysis for Measurements

	Slope	Intercept	R^2	*P* Value
WR-MR				
M	0.89	−0.37	0.79	<0.001
J_0	−0.08	−0.01	0.01	0.44
J_{45}	−0.27	0.02	0.06	0.01
WR-CR				
M	0.87	−0.63	0.76	<0.001
J_0	−0.07	−0.01	0.01	0.53
J_{45}	−0.02	−0.01	0.01	0.84

WR, WASCA refraction; MR, manifest refraction; CR, cycloplegic refraction.

Agreement Analysis

The agreement of each parameter is shown in Figure 2 using Bland-Altman plots. The mean error (error = WASCA – subjective value) of each component between the two methods is shown in Table 3. M and B value were significantly lower in WR than in CR (univariate paired *t* test), which is consistent with the fact that the 95% confidence intervals (CIs) of the mean $E_{W\text{-}C}$ did not include zero. No difference was found between WR and MR in any component.

For the B value, the mean $E_{W\text{-}M}$ was 0.18 ± 1.00 ($P = 0.09$), and $E_{W\text{-}C}$ was −0.64 ± 1.03 D ($P < 0.001$). In $E_{W\text{-}M}$, 55.0% of the eyes were within 0.5 D and 80.9% were within 1.0 D. In $E_{W\text{-}C}$, 45.0% of eyes were within 0.5 D and 70.8% were within 1.0 D.

Subgroup Comparisons

In the subgroup comparisons, WR tended to overestimate MR with hyperopia increase. In contrast, WR underestimated CR regardless of the hyperopia level (Table 4).

Discussion

This study aimed to compare WR and MR, as well as CR in hyperopia measurements. The results revealed that compared with CR, MR was more consistent with WR. WR generally underestimated CR. The variation among different components merits discussion.

The results showed no difference between MR and WR, while the M was lower in WR than in CR. Unlike myopia, hyperopia involves greater accommodation lag, and patients with hyperopia may have a defect of blur sensitivity.[10] Considering this, we analyzed both CR and MR. In agreement with clinical experience, CR was highly correlated with MR and showed a higher hyperopia level. Although WR was obtained after cycloplegia, it tended to underestimate the hyperopia level of CR.

In contrast to our results, Reinstein et al.[4] added an extra −0.4 D to the MR to compensate for the accommodation, resulting in a higher M value with the WASCA method. We believe that different levels of hyperopia correspond to different accommodation abilities. As the subgroup comparisons revealed, with higher hyperopia level, the M error between WR and MR increased. The M error did not show a significant difference between WR and CR among the subgroups, demonstrating that accommodation affects the error in MR analysis. Similar results were verified by the study by Hashemi et al.[11] study where higher hyperopia led to lower agreement between the two refraction methods.

Although WR showed no difference with MR in any component, the agreements between the two methods were beyond ±1.0 D, and the LoAs between WR and CR were beyond ±1.0 D, which are not clinically good. In contrast, in myopia measurement, Reinstein et al.[7] demonstrated high concordance between WR and MR, and the mean errors for the three vector components were within 0.25 D. Zhu et al.[5] also identified a high agreement between WR and MR in Chinese adults with myopia. The J_0 and J_{45} were highly correlated between the two methods in myopia measurement,[5,7] unlike the negative results in this study. It may be concluded that WASCA is not a suitable replacement of subjective refraction for cylinder assessment in hyperopia measurement.

For myopic measurements, Reinstein et al.[7] obtained an absolute dioptric error (ADE) of 0.43 D. Huelle et al.[6] considered both myopia and hyper-

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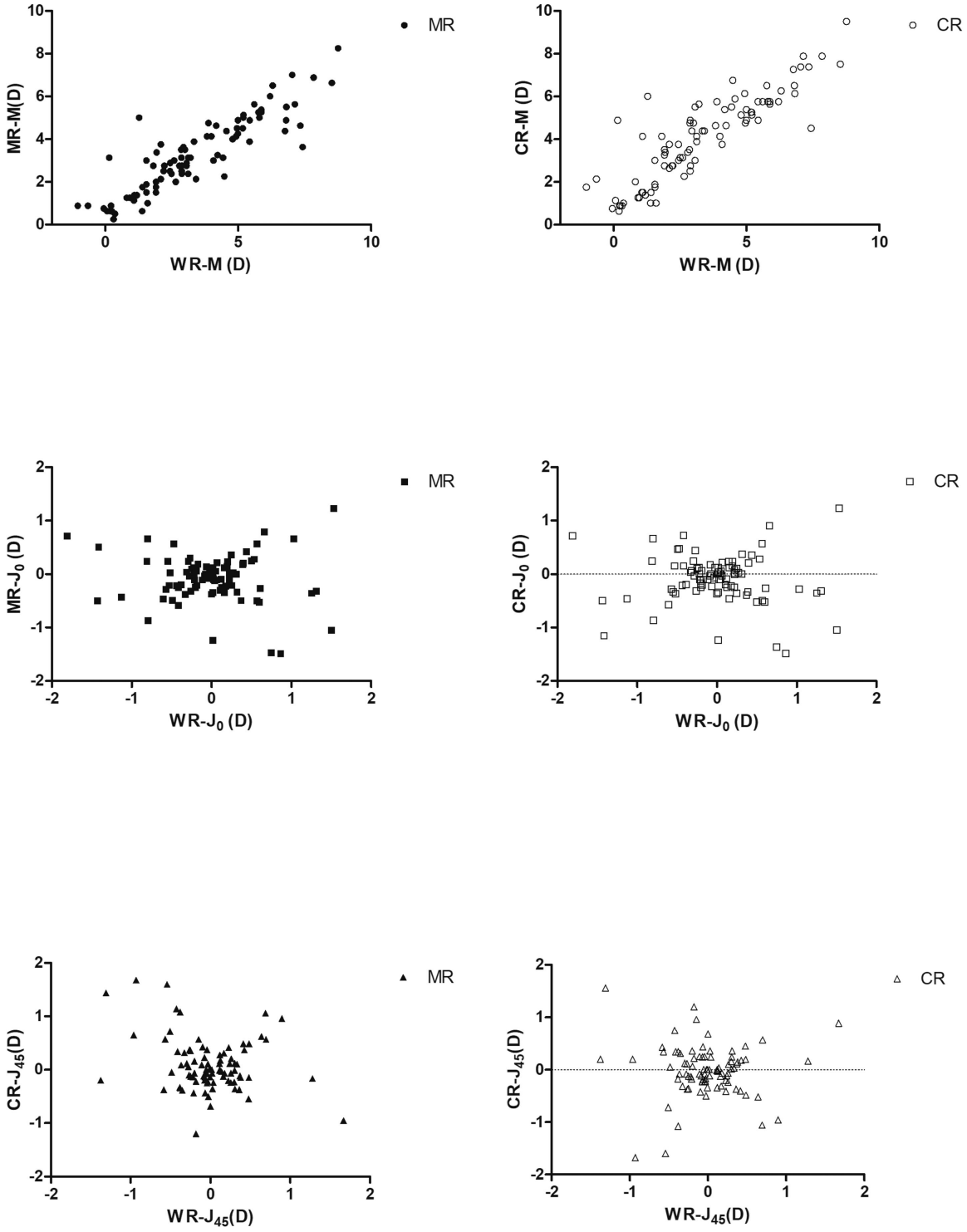

Figure 1. Scatter plot of vector components between WR and CR/MR. WR, wavefront supported custom ablation refraction; D, diopter.

opia in the analysis, and the result obtained was 1.25 D of ADE; this result was attributed to "hyperopic bias." Accordingly, our results showed that ADE was 0.18 D in MR and −0.68 D in CR. The 95% CI also revealed better accordance between WR and MR than between WR and CR. The discrepancy with regard to the study by Huelle et al.[6] may be attributed to age distribution (65.9 years), although direct evidence of the effect of age on WASCA accuracy is lacking.

One limitation of this study is that the enrolled eyes had no pure hyperopia correction. A greater sample size in the future would be helpful to clarify the

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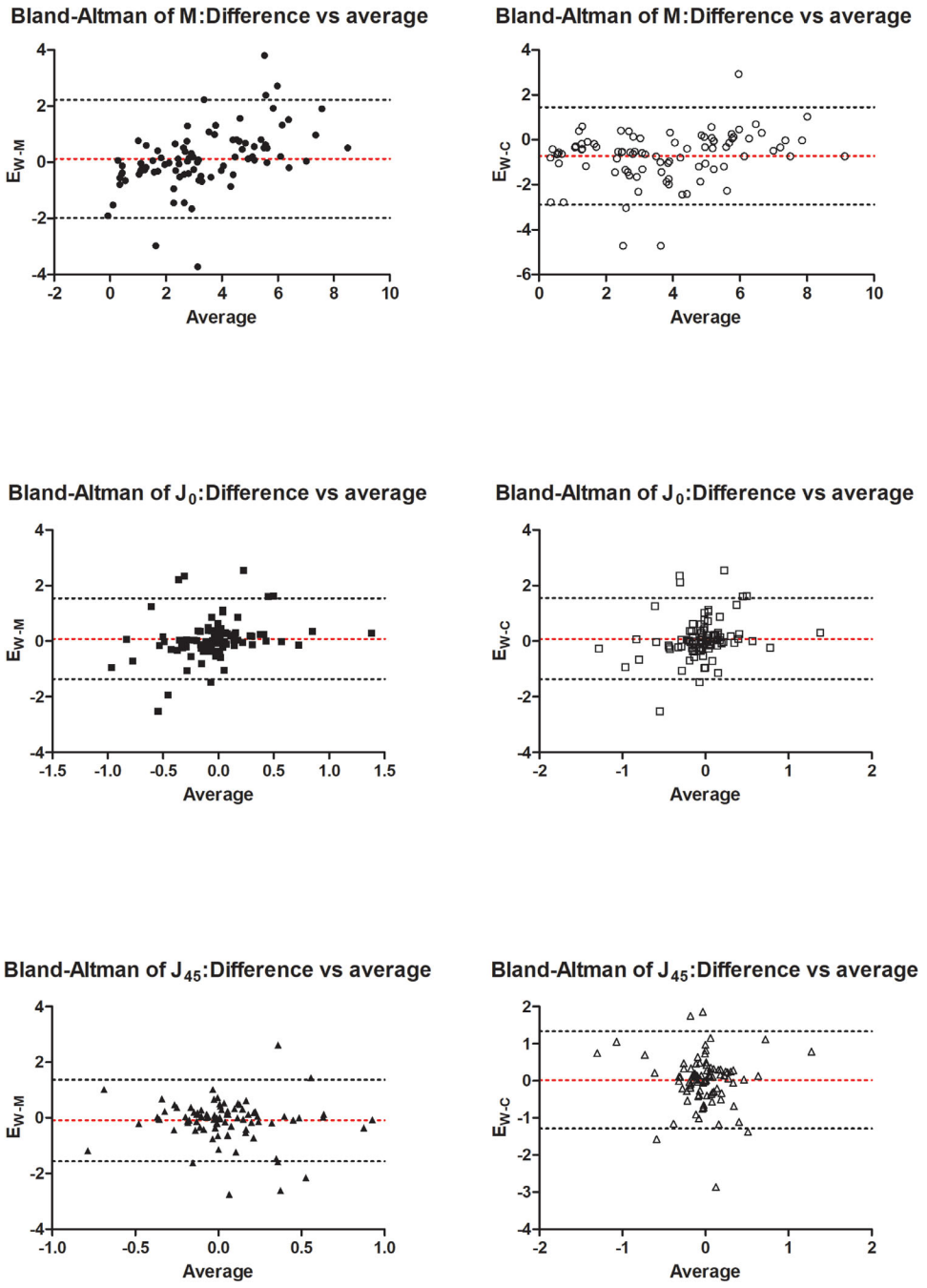

Figure 2. Bland–Altman plots of the difference between WR and CR/MR The *red line* indicates the mean difference between two methods, and the *outer lines* indicate the values of the limits of agreement. WR, wavefront supported custom ablation refraction.

accuracy on various astigmatism levels. Although all enrolled eyes had CDVA equal to or better than 20/25, and patients with apparent strabismus were excluded, we did not measure if there was mild or intermittent strabismus, because cyclotorsion of the eye may influence the fixation during WASCA measurement.

This study did not aim to challenge the necessity of WASCA in clinical practice, which is still regarded as a reference test before or after subjective refraction. There is no gold standard for refraction measurements, and even subjective refraction varies among different optometrists. To reduce such interobserver variation, the measurements were performed by one trained optometrist for CR and MR and another for WR.

In summary, in hyperopia measurement, WASCA may act as a reference to MR and generally underestimate the CR. The agreement between WASCA and

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Table 3. Difference of Each Component Between Two Measurements

		Mean ± Standard Deviation	95% Confidence Interval	*P*	LoA
M	$E_{W\text{-}M}$	0.12 ± 1.07	−0.11, 0.35	0.29	−1.98,2.22
	$E_{W\text{-}C}$	−0.72 ± 1.11	−0.95, −0.48	<0.001	−2.89,1.45
J_0	$E_{W\text{-}M}$	0.08 ± 0.74	−0.07, 0.24	0.30	−1.37,1.54
	$E_{W\text{-}C}$	0.09 ± 0.74	−0.07, 0.25	0.27	−1.37,1.55
J_{45}	$E_{W\text{-}M}$	−0.09 ± 0.75	−0.25, 0.06	0.24	−1.56,1.37
	$E_{W\text{-}C}$	0.02 ± 0.67	−0.12, 0.16	0.82	−1.29,1.33
B	$E_{W\text{-}M}$	0.18 ± 1.00	−0.03, 0.39	0.09	—
	$E_{W\text{-}C}$	−0.64 ± 1.03	−0.85, −0.42	<0.001	—

$E_{W\text{-}M}$, error (WASCA–manifest refraction); $E_{W\text{-}C}$, error (WASCA–cycloplegic refraction); M, spherical equivalent; B, overall blurring strength of a vector refraction; LoA, limits of agreement.

Table 4. Subgroups Comparisons of M Error Between WASCA and MR and CR

	Low (n = 26)	Moderate (n = 34)	High (n = 30)	*P*
$E_{W\text{-}M}$	−0.25 ± 0.59	0.08 ± 1.20	0.47 ± 1.14	0.04
$E_{W\text{-}C}$	−0.77 ± 0.94	−0.99 ± 1.22	−0.37 ± 1.04	0.08

$E_{W\text{-}M}$, error (WASCA–manifest refraction); $E_{W\text{-}C}$, error (WASCA–cycloplegic refraction); M, spherical equivalent.

subjective refraction is not clinically good in hyperopia measurement.

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