Original Article

Comparison of refractive assessment using Hartmann-Shack and ray-tracing wavefront aberrometry, autorefraction, and subjective refraction

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ABSTRACT

Background: Accurate objective assessment of refractive error is essential for efficient clinical refraction and optimal spectacle prescription, particularly with the growing use of wavefront-based technologies in contemporary ophthalmic practice. We aimed to compare mean spherical-equivalent measurements obtained using subjective refraction, conventional autorefractometry, Hartmann–Shack wavefront aberrometry (WASCA), and ray-tracing wavefront aberrometry (iTrace), and to determine which objective modality showed the smallest absolute mean bias relative to subjective refraction.

Methods: This study included healthy adults aged 18–30 years, recruited at Nethradhama Superspeciality Eye Hospital, Bengaluru, India, between October 2021 and June 2022. Participants underwent comprehensive ophthalmic examination followed by refractive assessment using subjective refraction, autorefractometry, WASCA Hartmann-Shack wavefront aberrometry, and iTrace ray-tracing wavefront aberrometry under non-cycloplegic conditions. Spherical equivalent (SE) measurements obtained by the four modalities were compared using repeated measures analysis of variance with Tukey honestly significant difference post hoc testing.

Results: The study cohort comprised 60 healthy adults (120 eyes) aged 18–30 years, 24 males (40%) and 36 females (60%), with a mean (standard deviation [SD]) age of 21.4 (1.4) years. Significant differences in SE measurements were observed among the four modalities for both right eyes (RE) and left eyes (LE) (both $P < 0.05$). In the RE, mean (SD) SE values were −0.65 (0.81) D for subjective refraction, −0.74 (0.89) D for autorefractometry, −0.98 (0.88) D for WASCA, and −1.15 (1.26) D for iTrace. Corresponding LE values were −0.54 (0.92) D, −0.67 (0.79) D, −0.94 (0.84) D, and −1.24 (0.97) D, respectively. Post hoc analysis revealed significant differences between subjective refraction and both WASCA and iTrace measurements in both eyes (all $P < 0.05$), whereas differences between subjective refraction and autorefractometry were not statistically significant (both RE and LE $P > 0.05$).

Conclusions: Autorefractometry showed the smallest absolute mean bias relative to subjective manifest refraction, compared with Hartmann–Shack and ray-tracing wavefront aberrometry. Both aberrometers tended to produce more myopic refractive estimates. On the basis of mean bias, autorefractometry may provide a useful initial estimate for subsequent subjective refinement. However, individual-level agreement and clinical efficiency were not evaluated, and subjective refraction remains necessary for determining the final spectacle prescription.

KEYWORDS

refractive error, hypermetropia, myopias, myopic astigmatisms, hyperopic astigmatism, mixed astigmatisms, vision test, ocular refraction, subjective refraction, retinoscopies, autorefractometer, aberrometries, optometry diagnostic techniques

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INTRODUCTION

Subjective refraction remains the reference standard for determining spectacle prescriptions, as its endpoint—the lens combination that provides the best-corrected visual acuity—is firmly established through longstanding clinical practice and convention [1–4]. Although subjective refraction can be performed using relatively simple equipment, including trial lenses, a trial frame, and a Snellen visual acuity chart [5], objective refractive assessment methods are routinely employed to guide, refine, and expedite the procedure [6].

Retinoscopy and autorefractometry constitute the most commonly utilized objective techniques for estimating refractive error prior to subjective refinement [7]. Autorefractometers have assumed an increasingly prominent role in contemporary ophthalmic practice thanks to their rapid acquisition time, ease of operation, and high repeatability [8–10]. In routine clinical workflows, subjective refraction is typically initiated using baseline measurements derived from autorefraction or retinoscopy. Nevertheless, accommodative fluctuations may introduce clinically relevant variability, particularly in younger individuals, necessitating careful interpretation of measurements obtained under both cycloplegic and non-cycloplegic conditions [2, 4, 9].

Wavefront aberrometers objectively measure monochromatic ocular aberrations using wavefront sensing. Although primarily developed for the analysis of higher-order aberrations, including coma, trefoil, and spherical aberration, these devices are also capable of measuring second-order refractive errors analogous to those obtained using conventional autorefractometry [11, 12]. Commercially available aberrometers principally employ two distinct optical principles for wavefront reconstruction: the Hartmann-Shack wavefront sensing system, exemplified by the WASCA aberrometer (Carl Zeiss Meditec AG, Jena, Germany), and ray-tracing aberrometry, represented by the iTrace system (Tracey Technologies, Hoya, Japan) [13–15]. These technologies differ fundamentally in their optical sampling and wavefront reconstruction strategies, potentially influencing refractive measurements and their agreement with subjective refraction.

Although several investigations have independently evaluated the agreement between subjective refraction and individual objective refractive assessment modalities [7, 8, 16, 17], studies directly comparing subjective refraction, conventional autorefractometry, Hartmann-Shack aberrometry, and ray-tracing aberrometry within the same study population remain limited [18]. Moreover, evidence derived from Indian populations is comparatively scarce. Accordingly, the present study was designed to compare mean spherical-equivalent (SE) measurements obtained using subjective refraction, autorefractometry, the WASCA Hartmann–Shack aberrometer and the iTrace ray-tracing aberrometer in healthy young adults, and to determine which objective modality showed the smallest absolute mean bias relative to subjective refraction.

METHODS

This prospective comparative clinical study was conducted between October 2021 and June 2022 at Nethradhama Superspeciality Eye Hospital in collaboration with Nethradhama School of Optometry in Bengaluru, India. Healthy adult participants were consecutively recruited during the study period. The study protocol received approval from the Institutional Review Board of Nethradhama Superspeciality Eye Hospital prior to study initiation. Written informed consent was obtained from all participants following a detailed explanation of the study objectives, examination procedures, and the voluntary nature of participation. Participants were informed of their right to withdraw from the study at any stage without prejudice or consequence. All study procedures were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Eligible participants were healthy adults aged 18–30 years with spherical refractive errors ranging from −3.00 to +3.00 diopters (D), astigmatism not exceeding −3.00 D cylinder, and corrected distance visual acuity (CDVA) of 6/9 or better in both eyes. Exclusion criteria were a history of ocular surgery; clinically significant corneal or lenticular opacity; keratoconus or other corneal ectatic disorders; strabismus; amblyopia; nystagmus; posterior segment pathology; or systemic diseases known to affect ocular health, including diabetes mellitus and hypertension. Participants with a natural pupil diameter < 5 mm, which may compromise the quality and reliability of wavefront aberrometry measurements [19], were also excluded. Individuals who were unable to maintain stable fixation during refractive and aberrometric assessments were not enrolled in the study.

To confirm eligibility for inclusion in the study, all participants underwent a standardized comprehensive ophthalmic examination prior to enrolment. CDVA was assessed monocularly using a Snellen visual acuity chart projected at 6 m, with measurements initially recorded in decimal notation and subsequently converted to logarithm of the minimum angle of resolution (logMAR) values for statistical analysis. Objective refractive assessment was performed using streak retinoscopy (Heine Beta 200 Streak Retinoscope; Heine Optotechnik GmbH, Herrsching, Germany) and autorefractometry (Topcon RM-8900; Topcon Co., Tokyo, Japan) [20]. Detailed anterior segment evaluation was conducted using slit-lamp biomicroscopy (Haag-Streit BX 900; Haag-Streit AG, Koeniz, Switzerland), while intraocular pressure was measured using a Perkins-type handheld applanation tonometer (Perkins®, Kowa Co., Tokyo, Japan). Dilated posterior segment examination, including fundoscopy, was performed to rule out retinal or optic nerve pathology.

Objective refractive measurements were subsequently obtained using three instruments: a conventional autorefractometer (Topcon RM-8900; Topcon Co., Tokyo, Japan) [20], a Hartmann-Shack wavefront aberrometer (WASCA;

Carl Zeiss Meditec AG, Jena, Germany) [14], and a ray-tracing wavefront aberrometer (iTrace; Tracey Technologies/Hoya, Japan) [15]. Subjective refraction was performed using a trial frame, trial lens set, Heine Beta 200 streak retinoscope, and Jackson cross-cylinder lenses.

For each participant, three consecutive measurements were obtained with the autorefractometer and each aberrometer, and the mean value was used for subsequent analysis. All refractive assessments were performed under non-cycloplegic conditions in a standardized dimly illuminated examination room to facilitate a physiological pupil diameter of at least 5 mm. Subjective refraction was conducted by an experienced optometrist who was masked to the autorefractometry findings. Retinoscopy findings or the participant's habitual spectacle prescription were used as the initial reference point for refinement. Final subjective refraction was refined using the Jackson cross-cylinder technique and the maximum plus for maximum visual acuity endpoint [21–23].

To minimize potential order effects, the sequence of objective measurements obtained with the autorefractometer, WASCA aberrometer, and iTrace aberrometer was randomized for each participant using a computer-generated randomization schedule prepared before study initiation. Allocation sequences were concealed in sequentially numbered sealed envelopes that were opened immediately prior to examination. Subjective refraction was consistently performed after completion of all objective assessments to avoid bias arising from prior knowledge of instrument-derived refractive values. For each modality, spherical equivalent (SE), calculated as sphere + (cylinder/2), was derived for both eyes and used for comparative analysis [7].

Statistical analyses were performed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA). Distribution of continuous variables was assessed for normality using the Kolmogorov-Smirnov test. Descriptive statistics are presented as mean (standard deviation [SD]) for continuous variables and as frequency (percentage) for categorical variables. Comparisons of SE measurements obtained by subjective refraction, autorefractometry, WASCA Hartmann-Shack aberrometry, and iTrace ray-tracing aberrometry were performed using repeated measures analysis of variance (ANOVA). When the overall ANOVA demonstrated statistical significance, post hoc pairwise comparisons were conducted using Tukey's honestly significant difference (HSD) test to adjust for multiple comparisons. To evaluate systematic bias between autorefractometry and subjective refraction, mean bias was calculated as autorefraction minus subjective refraction; therefore, negative values indicated a more myopic estimate by the objective modality. All statistical tests were two-tailed, and a P-value < 0.05 was considered statistically significant.

RESULTS

A total of 120 eyes from 60 participants were included in the final analysis. The study cohort comprised 24 males (40%) and 36 females (60%), with a mean (SD) age of 21.4 (1.4) years.

Repeated measures ANOVA yielded statistically significant differences in SE measurements among the four refractive assessment modalities for both right eyes (RE) (P = 0.007) and left eyes (LE) (P < 0.001). For the RE, the mean (SD) SE values were −0.65 (0.81) D for subjective refraction, −0.74 (0.89) D for autorefractometry, −0.98 (0.88) D for WASCA Hartmann-Shack aberrometry, and −1.15 (1.26) D for iTrace ray-tracing aberrometry. Corresponding values for the LE were −0.54 (0.92) D, −0.67 (0.79) D, −0.94 (0.84) D, and −1.24 (0.97) D (Table 1).

Post hoc pairwise analysis revealed that SE measurements obtained by both WASCA and iTrace differed significantly from those obtained by subjective refraction in both eyes (all P < 0.05). In contrast, no statistically significant difference was observed between subjective refraction and autorefractometry for either eye (RE: P = 0.160; LE: P = 0.297) (Table 1).

In both eyes, the mean SE values obtained using wavefront aberrometry were more myopic than those obtained using subjective refraction. The iTrace system showed the greatest absolute mean bias relative to subjective refraction, whereas autorefractometry showed the smallest absolute mean bias (Table 2).

Table 1. Comparison of spherical equivalent measurements obtained by four refractive assessment modalities

Eye	SR	Autorefraction	WASCA aberrometry	iTrace aberrometry	[1] *P*-value
RE SE (D), Mean ± SD	−0.65 ± 0.81	−0.74 ± 0.89	−0.98 ± 0.88	−1.15 ± 1.26	**0.007**
[2] ***P*-value**		0.160	**0.028**	**0.001**	
LE SE (D), Mean ± SD	−0.54 ± 0.92	−0.67 ± 0.79	−0.94 ± 0.84	−1.24 ± 0.97	**< 0.001**
[2] ***P*-value**		0.297	**< 0.001**	**< 0.001**	

Abbreviations: SR, subjective refraction; D, diopters; LE, left eye; RE, right eye; SD, standard deviation. Note: *P*-values <0.05 are shown in bold; [1] *P*-values were derived from repeated measures analysis of variance (ANOVA) comparing SR, autorefraction, WASCA aberrometry, and iTrace aberrometry; [2] *P*-values represent Tukey's honestly significant difference (HSD) post hoc comparisons with SR as the reference method.

Table 2. Mean bias in SE measurements obtained using three objective refractive assessment modalities relative to SR

Modality versus SR	Autorefraction	WASCA aberrometry	iTrace aberrometry
RE (D), Mean bias of SE	−0.09 D	−0.33 D	−0.50 D
LE (D), Mean bias of SE	−0.13 D	−0.40 D	−0.70 D

Abbreviations: SE, spherical equivalent; SR, subjective refraction; D, diopters; LE, left eye; RE, right eye. Note: Mean bias was calculated as the objective measurement minus subjective refraction; therefore, negative values indicated a more myopic estimate by the objective modality.

DISCUSSION

The principal finding of this study was that autorefractometry showed the smallest absolute mean bias relative to subjective refraction among the three objective modalities evaluated. This finding suggests that autorefractometry may provide a useful initial estimate for subsequent subjective refinement. Both WASCA and iTrace produced more myopic mean SE values than subjective refraction in both eyes, a finding that has important implications for preoperative screening and spectacle prescription workflows.

Our findings are broadly consistent with those of Bennett et al. [24], who reported closer agreement between subjective refraction and measurements obtained using the Nidek 530-A autorefractor than between subjective refraction and the Nidek OPD-II Scan wavefront aberrometer. Their cohort comprised 60 adults aged 18–59 years with visual acuity of 20/25 or better, clear ocular media, and no known corneal or retinal pathology [24]. Similarly, Davidova et al. [18] compared subjective refraction with autorefractometry and both Hartmann–Shack and ray-tracing aberrometry. They reported that although all three objective modalities could provide useful starting values for subjective refinement, their agreement with subjective refraction varied according to instrument type and optical characteristics. In their cohort, autorefractometry demonstrated the closest overall agreement with subjective refraction for several refractive parameters [18]. In the present study, autorefractometry showed the smallest absolute mean bias relative to subjective refraction.

Although Saad and Frings reported excellent preoperative agreement between wavefront aberrometry and subjective refraction in refractive surgery candidates [13], WASCA showed a negative mean SE bias relative to subjective refraction in the present study. This difference between studies suggests that wavefront-derived mean refractive estimates may vary according to patient population, measurement conditions and clinical context.

Differences between wavefront aberrometry and subjective refraction have been attributed, at least in part, to the incorporation of higher-order aberrations into wavefront-derived refractive calculations, whereas subjective refraction represents a functional optimization of lower-order refractive correction based on visual performance [24–26]. Cooper et al. [25] reported that the Z-View aberrometer tended to overcorrect astigmatism below −1.25 D cylinder, whereas autorefractometry overcorrected astigmatism below −0.75 D cylinder, indicating modality-specific tendencies toward refractive overestimation at lower astigmatic magnitudes [25]. These observations may partly explain the divergence between aberrometry-derived and subjective SE measurements observed in the present study.

Lin et al. [27] compared cycloplegic wavefront refraction obtained using the Allegretto Wave Analyzer with cycloplegic autorefraction (RM-A7000; Topcon, Tokyo, Japan) and subjective manifest refraction, and reported strong correlations between both objective modalities and subjective refraction. However, cycloplegic autorefraction revealed closer correspondence with subjective manifest refraction than wavefront refraction, with no significant difference in SE between autorefraction and subjective refraction, whereas wavefront refraction showed a small but significant myopic shift [27]. Our findings under non-cycloplegic conditions in young adults with a mean age of 21.4 years may have been influenced by accommodation [28–30], therefore future studies incorporating cycloplegia may help further clarify the relationship between objective and subjective refractive measurements in this age group.

The absolute mean biases between autorefractometry and subjective refraction were small (RE: 0.09 D; LE: 0.13 D). However, mean bias alone does not characterize individual-level agreement or establish the clinical efficiency of autorefractometry as a starting point for subjective refinement. Accordingly, autorefractometry may provide a useful objective baseline for subjective refinement, particularly in high-volume ophthalmic settings such as those commonly encountered in India [31, 32]; however, its clinical efficiency and practical advantages over the other modalities require direct evaluation.

A notable strength of the present study is the direct within-subject comparison of subjective refraction, autorefractometry, Hartmann-Shack aberrometry, and ray-tracing aberrometry under standardized examination conditions. In addition, randomization of the sequence of objective measurements and masking of subjective refraction to autorefractometry findings helped minimize potential measurement and observer bias. The present study has several limitations that should be acknowledged. First, all measurements were obtained under non-cycloplegic conditions, which may have introduced accommodative variability and influenced refractive measurements, particularly during fixation on the internal targets used by the wavefront aberrometers. Second, the relatively modest sample size and single-center design may limit generalizability of the findings. In addition, the study population was restricted to healthy young adults with low-to-moderate refractive errors; therefore, the results may not be directly generalizable to older individuals, patients with higher ametropia, or those with ocular pathology. Future investigations incorporating cycloplegic measurements, larger multicenter cohorts, and a broader age distribution would help clarify the comparative performance of objective refractive assessment modalities across diverse clinical settings. Subgroup analyses according to refractive error magnitude and refractive subtype, including myopia, hyperopia, and astigmatism, may further improve understanding of the clinical applicability and limitations of individual instruments.

CONCLUSIONS

In healthy young adults, autorefractometry showed the smallest absolute mean SE bias relative to subjective manifest refraction among the three objective modalities evaluated. Both the Hartmann–Shack WASCA and ray-tracing iTrace aberrometers produced more myopic mean estimates, with iTrace showing the greatest absolute mean bias. On the basis of mean bias, autorefractometry may provide a useful initial estimate for subsequent subjective refinement. However, individual-level agreement and the clinical efficiency of using each modality as a starting point were not evaluated. Therefore, subjective refraction remains necessary for determining the final spectacle prescription. Although wavefront aberrometry provides additional information about higher-order aberrations relevant to refractive assessment and surgical planning, further agreement and clinical-efficiency analyses are required before drawing definitive conclusions about its comparative suitability for routine refraction workflows.

ETHICAL DECLARATIONS

Ethical approval: The study protocol received approval from the Institutional Review Board of Nethradhama Superspeciality Eye Hospital prior to study initiation. Written informed consent was obtained from all participants following a detailed explanation of the study objectives, examination procedures, and the voluntary nature of participation. Participants were informed of their right to withdraw from the study at any stage without prejudice or consequence. All study procedures were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

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