

ORIGINAL RESEARCH ARTICLE

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IMPACT OF PUPIL APERTURE ON AGREEMENT BETWEEN OBJECTIVE AND SUBJECTIVE REFRACTION

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Abstract

Wavefront-based objective refraction may vary with analysis aperture because larger pupils increase the contribution of higher-order aberrations. The objective of this study was to assess the agreement between objective refraction derived at simulated 3-mm and 5-mm analysis apertures and subjective refraction using the Zeiss i.Profiler Plus. This observational study included 200 adults aged 18-50 years. Objective refractive values for simulated 3-mm and 5-mm analysis apertures were derived from the same i.Profiler acquisition and did not represent physiologically measured pupil sizes after light adaptation. Subjective refraction was performed using the Zeiss Visuphor 500. Agreement was evaluated using Bland-Altman analysis. Results showed that the mean spherical equivalent refraction (SER) was -0.82 ± 1.70 D at 3 mm, -0.98 ± 1.68 D at 5 mm, and -0.67 ± 1.49 D subjectively. For SER, the 3-mm aperture showed slightly narrower limits of agreement (-0.92 to $+0.62$ D) than the 5-mm aperture (-1.05 to $+0.43$ D). For cylinder, the 5-mm aperture showed marginally narrower limits of agreement (-0.67 to $+0.18$ D) than the 3-mm aperture (-0.72 to $+0.19$ D). In conclusion, the 3-mm analysis aperture showed slightly closer agreement for spherical measurements, whereas the 5-mm aperture showed marginally closer agreement for cylindrical power. These differences were small and unlikely to be clinically meaningful.

Keywords: Pupil aperture; objective refraction; subjective refraction; agreement; Zeiss i.Profiler Plus

1. Introduction

Objective refraction has advanced rapidly over the last two decades, complementing clinical retinoscopy and subjective refraction. Wavefront aberrometers and modern autorefractors now provide high-resolution measurements of lower-order refractive error alongside higher-order aberrations (HOAs), enabling more individualized refractive management and potentially improving visual quality beyond high-contrast acuity. Among these, the Zeiss i.Profiler Plus can estimate refraction for different effective analysis apertures and quantify HOAs, providing profiles that approximate brighter (about 3 mm) and dimmer (about 5 mm) optical conditions [1-4].

Pupil size and analysis aperture are clinically important because enlarging the aperture increases the influence of HOAs on retinal image quality and can alter sphere, cylinder, and axis estimates derived from wavefront data [5-7]. Consequently, refractions derived at smaller and larger effective pupils may differ, and these differences can vary with baseline refractive error and ocular optics. Few studies have specifically examined how pupil aperture influences refractive measurements. Understanding how smaller and larger analysis apertures affect derived refraction may therefore be relevant when interpreting wavefront-based measurements in patients with task- or lighting-dependent visual complaints [8-13].

Building on this evidence, we assessed refractions derived at two effective analysis apertures (approximately 3 mm and 5 mm) using the i.Profiler Plus and evaluated whether any observed differences were clinically meaningful across refractive error categories (myopia, emmetropia, and hyperopia). This study aimed to determine the impact of analysis aperture on agreement between objective and subjective refraction.

2. Methods

Study design and participants:

This observational study was conducted at Zeiss Vision Center, Tirana, Albania, between February 2024 and September 2024. From a total of 1,300 screened individuals attending routine eye examinations, 200 participants were conveniently enrolled based on defined inclusion and exclusion criteria. Eligible participants were required to have no evidence of anterior or posterior segment pathology and to achieve a best-corrected visual acuity (BCVA) of 1.0 decimal (Snellen equivalent 6/6) in both eyes. Only individuals with refractive errors, i.e., myopia (< -0.50 D), hyperopia ($> +0.50$ D), astigmatism (< -0.75 D), or emmetropia (> -0.50 D to $< +0.50$ D), were included in this study [14]. Participants with any history of ocular surgery, ocular allergy, systemic disease affecting vision, or use of medications influencing accommodation were excluded.

Ethical approval:

The study adhered to the tenets of the Declaration of Helsinki and was approved by the Research Cell of Tirana Retina Institute with reference # TRI/Opt/20241. Written informed consent was obtained from all participants before enrollment.

Examination Protocol:

All participants underwent a comprehensive ophthalmic evaluation that included detailed medical and ocular history, assessment of visual acuity, slit-lamp biomicroscopy, and fundus examination. Objective refractive measurements were obtained using the Zeiss i.Profiler Plus (Carl Zeiss Meditec AG, Germany) under standardized illumination conditions. The device performs wavefront-based refractive analysis and computes refraction across different simulated pupil apertures. In this study, refractive values corresponding to 3 mm and 5 mm pupil diameters were extracted, representing approximations of photopic- and mesopic-related optical conditions, respectively, rather than measurements obtained after physiological light adaptation.

Measurements were based on a wavelength of 555 nm and a back vertex distance (BVD) of 12 mm [15]. The Zeiss i.Profiler Plus combines corneal wavefront and Placido-disc topography analysis using approximately 1,500 wavefront measurement points and 3,425 corneal topography points across 18 Placido rings spanning diameters from 2 to 7 mm. The system provides a measurement precision of approximately ± 0.05 D (± 0.01 mm) and reproducibility of ± 0.10 D (± 0.02 mm), with an acquisition time of approximately 0.2 seconds. Rather than providing a single refractive value, the system measures optical aberrations across the pupil and reconstructs the refractive profile of the eye using multiple sampling

points. This allows the software to mathematically calculate refractive outcomes for different analysis apertures (3 mm and 5 mm) from the same acquisition, as shown in Figure 1.

Visual acuity was assessed via a Zeiss Visuscreen version 2.9 wall-mounted digital screen at a standardized and calibrated distance of 4 meters from the subjects assessed during the study under normal room illumination. All the visual acuity measurements were recorded monocularly and binocularly, with and without glasses, using the Decimal acuity system as a standard acuity measurement in Albania. Distance refraction was assessed first and followed by near refraction.

Starting with the right eye, the best spherical lens was determined first using 0.25 D steps from the 3-mm measurement until best visual acuity was achieved. Jackson cross-cylinder axis refinement was then performed using 15°, 5°, 2°, and 1° steps, with the subject selecting the clearer option. Cylinder power was refined in 0.25 D steps, followed by refinement of the best-vision sphere using ± 0.25 D steps to obtain best-corrected visual acuity. The same procedure was followed for the left eye.

After monocular refraction, binocular balancing was performed using red and green filters. The best-vision sphere was further refined to optimize binocular comfort and visual acuity. Near refraction was performed for participants aged 40 years and older. Subjective refraction was performed using starting prescriptions derived from the 3-mm and 5-mm i.Profiler measurements, and best-corrected visual acuity was recorded for each condition. Interpupillary distance was measured automatically by the i.Profiler and manually for distance and near (40 cm) using a MOSCOT ruler in millimeters.

Figure 1. Zeiss i.Profiler refractive assessment printout for 3-mm and 5-mm analysis apertures

OD (right) Analysis Aperture (3.0) Refraction S = +0.35 D C = -0.39 D A = 165° Analysis Aperture (5.0) Refraction S = +0.07 D C = -0.36 D A = 148° Topography SteepK = 7.43mm / 73° FlatK = 7.50mm / 163°	OS (left) Analysis Aperture (3.0) Refraction S = +0.41 D C = -0.21 D A = 63° Analysis Aperture (5.0) Refraction S = +0.10 D C = -0.36 D A = 56° Topography SteepK = 7.43mm / 124° FlatK = 7.51mm / 34°
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Outcome measures: The primary outcomes were differences between objective and subjective refraction in spherical equivalent refraction (SER), cylindrical power, and cylindrical axis for the 3-mm and 5-mm analysis-aperture conditions.

Statistical analysis: Data from the right eye were included. Descriptive statistics (mean and standard deviation) were calculated for all refractive parameters. Differences between subjective and objective refraction for each analysis aperture (3 mm and 5 mm) were assessed using mean differences and paired-sample t-tests. Bland-Altman plots were used to evaluate agreement and variability between measurement methods, with 95% limits of agreement (LoA) calculated for SER, cylinder power, and axis. A p-value < 0.05 was considered statistically significant. All statistical analyses were performed using JASP statistical software (University of Amsterdam, the Netherlands).

3. Results

We included 200 participants, of whom 40% were male ($n = 80$) and 60% were female ($n = 120$). Mean age was 33.97 ± 10.16 years (range, 18-50 years). Mean SER was -0.82 ± 1.70 D for the 3-mm objective refraction, -0.98 ± 1.68 D for the 5-mm objective refraction, and -0.67 ± 1.49 D for subjective refraction. Table 1 presents the descriptive statistics.

Table 1. Objective refraction at 3-mm and 5-mm analysis apertures and subjective refraction

	3 mm Objective Refraction		5 mm Objective Refraction		Subjective Refraction	
	Mean	SD	Mean	SD	Mean	SD
Sph.Eq	-0.82	1.70	-0.98	1.68	-0.67	1.49
Sphere	-0.47	1.66	-0.65	1.64	-0.46	1.45
Cylinder	-0.69	0.60	-0.67	0.63	-0.43	0.57

Table 2 presents descriptive statistics for objective refraction measured at 3-mm and 5-mm analysis apertures and for subjective refraction across refractive groups. In myopic eyes, objective refraction was slightly more minus than subjective refraction, with mean values of -1.91 ± 1.24 D at 3 mm and -1.85 ± 1.26 D at 5 mm, compared with -1.75 ± 1.20 D subjectively. In hyperopic eyes, objective refraction similarly showed slightly higher plus values than subjective refraction.

Table 2. Descriptive statistics of objective and subjective refraction

Refraction Method	Refractive Status	N	Mean (D)	SD (D)
3 mm Objective Refraction	Myopia	112	-1.912	1.242
	Hyperopia	33	+1.567	1.163
	Emmetropia	55	-0.029	0.277
5 mm Objective Refraction	Myopia	128	-1.848	1.262
	Hyperopia	26	+1.665	1.228
	Emmetropia	46	-0.071	0.288
Subjective Refraction	Myopia	98	-1.754	1.201
	Hyperopia	30	+1.379	1.067
	Emmetropia	72	-0.056	0.178

Bland-Altman analysis was performed to assess agreement between objective and subjective refraction. In myopic eyes, objective refraction measured at the 5-mm analysis aperture showed narrower limits of agreement (-2.77 to $+2.65$ D) than the 3-mm analysis aperture. In hyperopic eyes, the 3-mm analysis aperture showed narrower limits of agreement than the 5-mm aperture. Table 3 and Figures 2-4 summarize the Bland-Altman analyses by refractive status.

Table 3. Bland-Altman agreement between objective and subjective refraction

Refractive Status	Pupil Size	Mean Difference (D)	Lower LoA (D)	Upper LoA (D)	LoA Width (D)	Better Agreement
Myopia	3 mm	-0.059	-3.082	+2.964	6.05	
	5 mm	-0.058	-2.765	+2.650	5.42	5 mm
Hyperopia	3 mm	+0.222	-2.068	+2.511	4.58	3 mm
	5 mm	+0.228	-2.256	+2.711	4.97	
Emmetropia	3 mm	+0.035	-0.520	+0.590	1.11	3 mm
	5 mm	+0.005	-0.682	+0.693	1.38	

Figure 2. Bland-Altman analysis of myopia

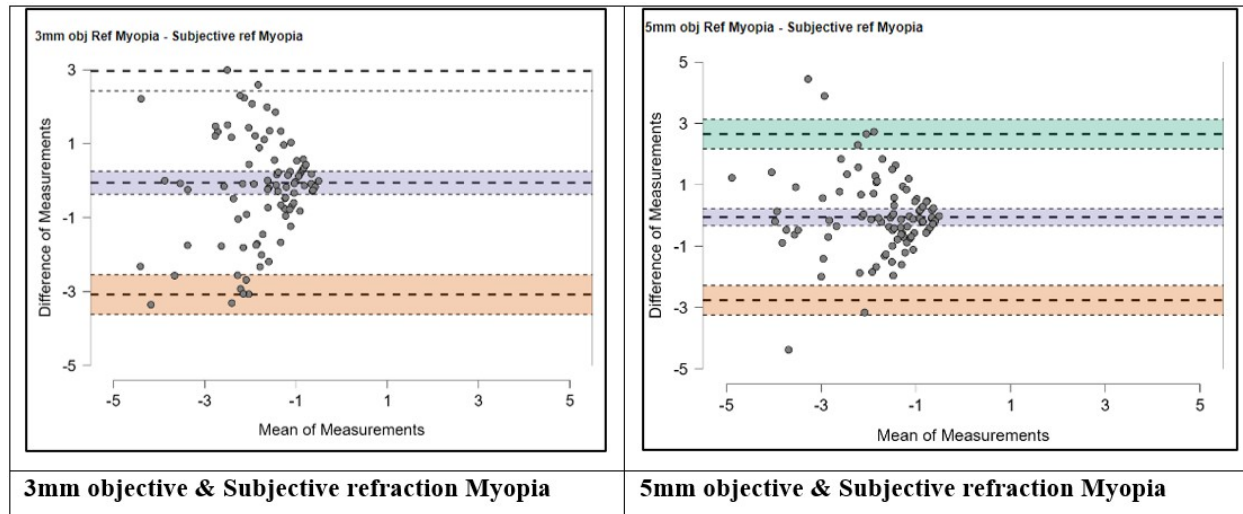
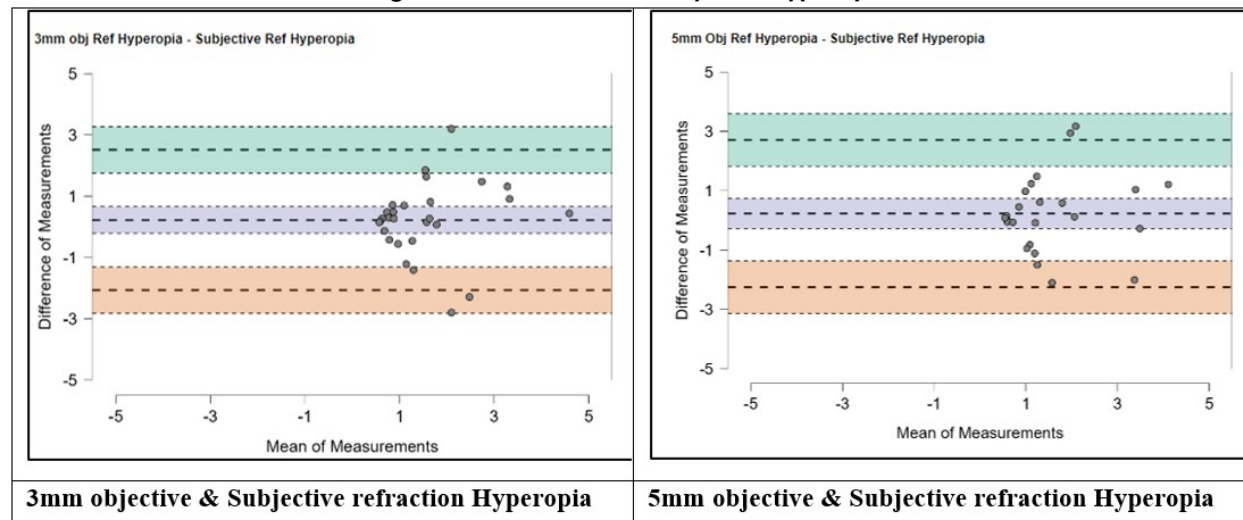


Figure 3. Bland-Altman analysis of hyperopia



Bland-Altman analysis was also performed for overall spherical equivalent refraction, spherical power, and cylindrical power. For SER, the 3-mm objective refraction showed narrower limits of agreement (-0.92 to +0.62 D) with a mean difference of -0.15 D compared with subjective refraction. The corresponding 5-mm comparison showed limits of agreement of -1.05 to +0.43 D and a mean difference of -0.31 D, as shown in Figures 5 and 6.

Figure 4. Bland-Altman analysis of emmetropia

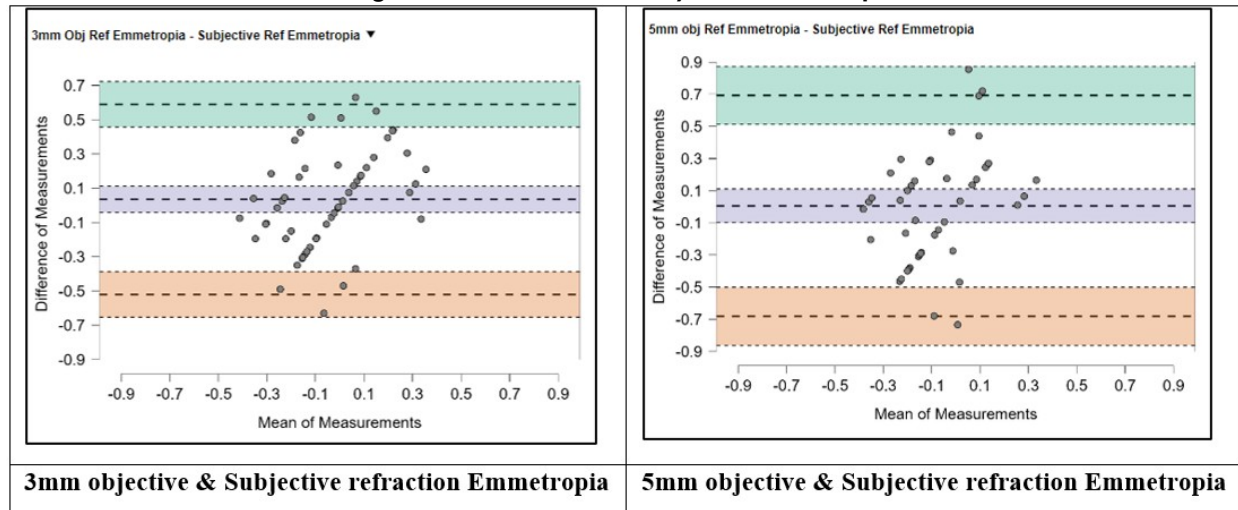
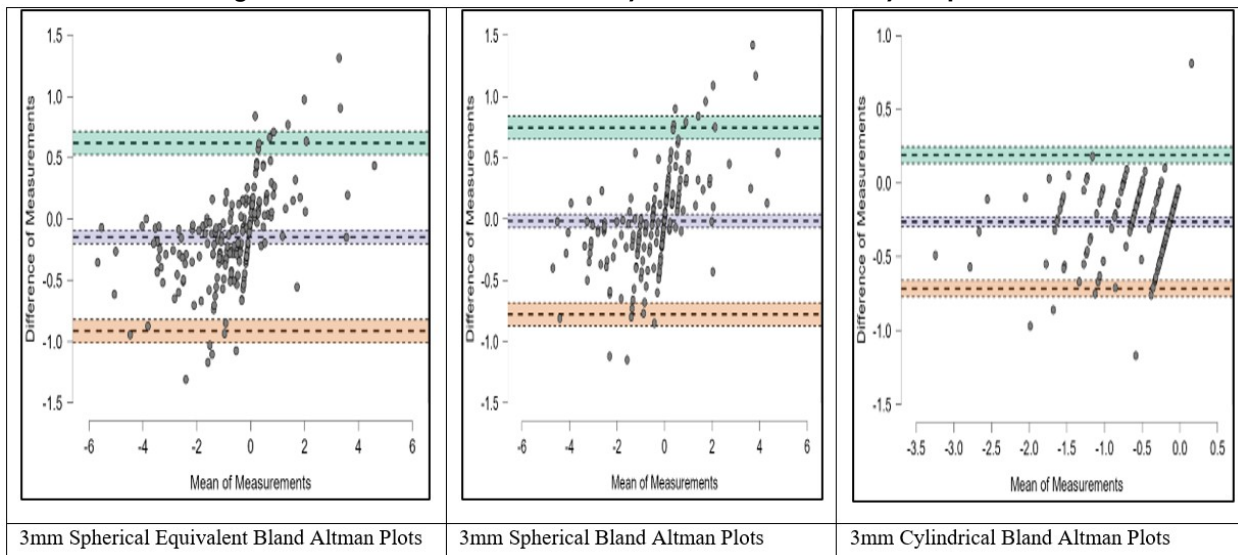


Figure 5. Overall Bland-Altman analysis for the 3-mm analysis aperture



For cylindrical power, the mean value was -0.69 ± 0.59 D for the 3-mm objective refraction and -0.67 ± 0.63 D for the 5-mm objective refraction. The mean subjective cylindrical power was -0.43 ± 0.57 D.

Bland-Altman analysis of cylindrical power showed a mean difference of -0.26 D between the 3-mm objective refraction and subjective refraction, with limits of agreement from -0.72 to $+0.19$ D. For the 5-mm analysis aperture, the mean difference was -0.24 D (95% CI, -0.27 to -0.21 D), with limits of agreement from -0.67 to $+0.18$ D. Thus, cylindrical power obtained at the 5-mm analysis aperture showed marginally closer agreement with subjective refraction than the 3-mm measurement, as shown in Figures 5 and 6.

For spherical power, the mean difference between the 3-mm objective refraction and subjective refraction was -0.02 D, with limits of agreement from -0.78 to $+0.75$ D. The corresponding 5-mm comparison showed a mean difference of -0.19 D and limits of agreement from -0.93 to $+0.55$ D. These results indicate slightly closer agreement for the 3-mm analysis aperture, as shown in Figures 5 and 6.

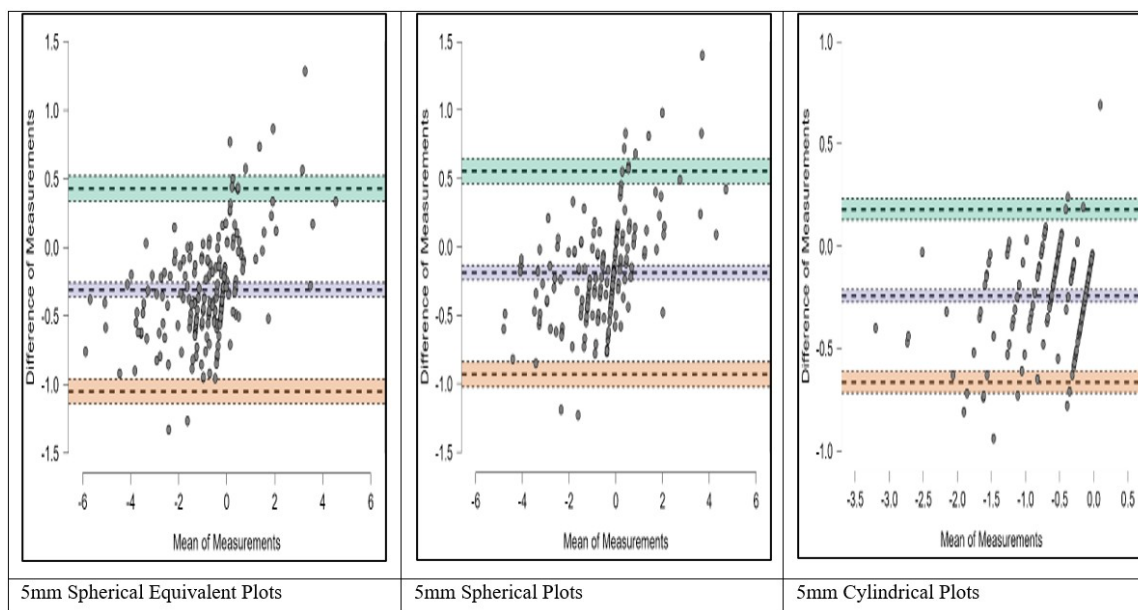
Table 4 presents Bland-Altman agreement by age group and analysis aperture. In participants aged 18-28 years, myopic eyes showed narrower limits of agreement at 3 mm (LoA width, 6.01 D) than at 5 mm (6.76

D). Among participants aged 29-39 years with hyperopia, the 5-mm aperture showed a marginally narrower LoA width than the 3-mm aperture (5.01 D vs. 5.11 D), whereas in the 40-50-year hyperopic group, the 3-mm aperture showed narrower limits (2.57 D vs. 5.59 D). In the 29-39-year emmetropic group, the 5-mm aperture also showed slightly narrower limits (1.09 D vs. 1.39 D). These subgroup differences should be interpreted cautiously because of the smaller sample sizes within age and refractive-status strata.

Table 4. Bland-Altman agreement by age group

Age group (years)	Refractive Status	Pupil Size	Mean Difference (D)	Lower LoA (D)	Upper LoA (D)	LoA Width (D)	Better Agreement
18-28	Myopia	3 mm	-0.106	-3.11	2.89	6.01	3 mm
		5 mm	-0.070	-3.44	3.30	6.76	
	Hyperopia	3 mm	-	-	-	-	
		5 mm	-	-	-	-	
	Emmetropia	3 mm	-0.076	-0.55	0.40	0.96	3 mm
		5 mm	-0.168	-0.55	0.36	1.06	
29-39	Myopia	3 mm	0.040	-3.140	3.220	6.36	3 mm
		5 mm	0.933	-3.719	5.584	9.30	
	Hyperopia	3 mm	0.452	-2.101	3.004	5.11	
		5 mm	0.378	-2.126	2.881	5.01	5 mm
	Emmetropia	3 mm	0.157	-0.536	0.850	1.39	5 mm
		5 mm	0.137	-0.407	0.681	1.09	
40-50	Myopia	3 mm	-0.05	-1.03	0.92	1.95	3 mm
		5 mm	-0.14	-3.06	2.77	5.83	
	Hyperopia	3 mm	0.25	-1.03	1.54	2.57	3 mm
		5 mm	0.17	-2.61	2.97	5.59	
	Emmetropia	3 mm	0.06	-0.49	0.62	1.13	3 mm
		5 mm	0.002	-0.64	0.64	1.28	

Figure 6. Overall Bland-Altman analysis for the 5-mm analysis aperture



4. Discussion

The results showed that objective refraction derived at the 3-mm analysis aperture demonstrated slightly closer agreement with subjective refraction for spherical power, whereas the 5-mm analysis aperture provided marginally closer agreement for cylindrical power.

This study expands on previous work evaluating agreement between Zeiss i.Profiler objective refraction and conventional subjective refraction by specifically examining the influence of analysis aperture. Earlier studies primarily compared the two techniques without varying the analysis aperture. Lebow and Campbell reported that the Zeiss i.Profiler tended to yield slightly more myopic SER than subjective refraction, with a mean difference of approximately 0.11 D, but did not assess the effect of analysis aperture [5]. Similarly, Müller et al. compared noncycloplegic objective refraction from the Zeiss i.Profiler Plus with cycloplegic subjective refraction in myopic children and found a consistent bias toward more myopic objective measurements [16]. Our findings are consistent with these reports. However, by analyzing two effective apertures (3 mm and 5 mm), we found that agreement with subjective refraction varied slightly with analysis aperture. The 3-mm aperture produced measurements that were closer to subjective spherical refraction, potentially reflecting optical conditions more similar to those used during subjective testing. The observed differences between the 3-mm and 5-mm apertures were small and are unlikely to be clinically meaningful in routine practice.

The small differences between objective and subjective refraction may be influenced by optical aberrations, including spherical and chromatic aberrations [17]. A larger pupil allows more peripheral rays to enter the eye, increasing the contribution of higher-order aberrations and potentially reducing retinal image quality. Iseli et al. reported a strong relationship between pupil-size-related refractive change and higher-order aberrations [18]. Several studies have further demonstrated the influence of pupil size on visual quality [19-22].

In this study, the cylindrical component derived at the 5-mm analysis aperture was marginally closer to subjective cylindrical power than the 3-mm measurement. Kobashi et al. reported that larger pupils can reduce optical quality in astigmatic eyes, although they did not compare 5-mm objective refraction with

subjective refraction [22]. Yamamoto et al. similarly reported that larger pupils can reduce retinal image quality in astigmatic eyes because the circle of least confusion increases with pupil size [23].

From a clinical perspective, the 3-mm analysis aperture may provide a useful starting point for subjective refinement of spherical refraction, whereas the 5-mm aperture may marginally better reflect cylindrical power. However, these differences were small and may not be clinically significant for routine practice. This study used a convenience sample of adults aged 18-50 years, and all measurements were obtained without cycloplegia. Therefore, the findings may not be generalizable to younger or pediatric populations, and further research is required in broader cohorts. Vector analysis was not performed for astigmatism. In addition, the 3-mm and 5-mm values were instrument-derived analysis apertures rather than direct physiological pupil measurements, and measurements were not repeated to assess test-retest variability.

5. Conclusion

Our study demonstrates that objective refraction values derived from the Zeiss i.Profiler Plus show overall agreement with subjective refraction. The 3-mm analysis aperture showed slightly closer agreement for spherical measurements, whereas the 5-mm aperture showed marginally closer agreement for cylindrical power. These differences were small and unlikely to be clinically meaningful.

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Author Contributions

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Conceptualization	✓	✓	✓	✓	✓
Methodology	✓	✓	✓	✓	-
Investigation	✓	✓	-	✓	-
Formal Analysis	✓	✓	-	-	-
Writing	✓	✓	✓	✓	✓
Supervision	✓	✓	-	✓	-
Visualization	✓	✓	✓	✓	✓

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