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ORIGINAL PAPER

Comparison of photorefraction, autorefractometry and retinoscopy in children

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Abstract Photorefractive devices have been evaluated for their effectiveness in detecting anisometropia, hyperopia, myopia, and astigmatism. We investigated the reliability of Plusoptix S08, the newest photoscreener, and Topcon autorefractometer by comparing them with cycloplegic retinoscopy. Plusoptix S08, cycloplegic retinoscopy, and cycloplegic autorefractometer measurements for 235 eyes of 118 children (59 female, 59 male) with a mean age of 4.9 ± 2.6 and median age of 5 years (range 1–12) were conducted. The Plusoptix S08 produced the following mean (±SD) results—spherical 0.27 ± 1.64, cylindrical power −0.81 ± 0.71, axis 89.73 ± 61.18, and spherical equivalent −0.05 ± 1.61. The cycloplegic retinoscopy produced the following mean (±SD) results—spherical 0.12 ± 1.35, cylindrical power −0.89 ± 0.71, axis 92.18 ± 68.39, and spherical equivalent −0.15 ± 1.31. The cycloplegic autorefractometer produced the following mean (±SD) results—spherical 0.16 ± 1.44, cylindrical power −0.88 ± 0.72, axis 90.86 ± 68.21, and spherical equivalent −0.12 ± 1.41. This study has shown that cycloplegic autorefractometer and retinoscopy results are similar and Plusoptix S08 is a very safe, easy-to-use and reliable screening method of refraction, especially for ophthalmologists unskilled in retinoscopy. Plusoptix S08 is a useful tool for estimating refraction in patients for whom conventional autorefraction is not an option.

Keywords Amblyopia · Photoscreening · Plusoptix · Refraction

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Introduction

Amblyopia is a preventable visual impairment of adults and children which affects 1.6–3.6 % of the population [1]. The prevalance of this disorder is higher where access to healthcare is limited [1–3]. Treatment is highly effective if started at an early age [1]. Photorefractive devices have been evaluated for their effectiveness in detecting anisometropia, hyperopia, myopia, and astigmatism [3–5]. Early pediatric vision screening is recommended by the American Academy of Pediatrics and the American Association of Pediatric Ophthalmology and Strabismus (AAPOS) as well as the European Strabismological Association and Societies (ESA) [6–8]. Population outcome studies support the use of preschool screening to reduce the prevalance of amblyopia [9, 10]. Retinoscopy (often in combination with cycloplegia) is commonplace for refracting very young children in most clinical practices today. Nonetheless, retinoscopy has some limitations because it (1) is mostly user-dependent; (2)

requires advanced clinical ophthalmic training; and (3) is mostly subject to inter-observer variability [11–13]. Using autorefractors in children presents its own problems, such as difficulty in maintaining the appropriate position of the child, ensuring head alignment, and achieving visual fixation on a target for a sufficient length of time [14]. Photoscreening may be a better option in children for whom these challenges prevent proper evaluation [15, 16].

Plusoptix S08 is the newest photoscreener designed specifically for children and disabled persons. Approved by the US Food and Drug Administration (FDA), Plusoptix S08 is a non-invasive method of measuring refractive data, pupil size, pupil distance, and gaze deviation in real time [16, 17]. Due to the large working distance, photorefraction is suitable for examining children and disabled patients. Because children do not have to put their head close to the device, they do not feel threatened by the examiner. Photorefraction also allows simultaneous examination of both eyes, thereby accelarating the measurement procedure [17].

The purpose of this study was to compare refraction measurements made in children with the latest-generation photoscreener Plusoptix S08 (Plusoptix GmbH, Nurnberg, Germany) and a cycloplegic autorefractometer (Topcon RM 8800; Topcon, Tokyo, Japan) with cycloplegic retinoscopy.

Materials and methods

Participants' parents provided informed consent and approval was obtained from our institution's human science ethics committee. The conduct of the study followed the tenets set forth in the Declaration of Helsinki.

Patients were excluded from the study if they had eccentric fixation, optical media opacity, or as per manufacturer of Plusoptix S08 recommendations, the refractive errors of the eyes did not exceed a maximum spherical range of −7.00 to +5.00 diopters (D) and a cylindrical range of −7.00 to +5.00 D. After these exclusions were made, 118 children (235 eyes) were included in the study and data for these children were used for all statistical analyses.

All patients underwent a complete ophthalmologic examination, including cover test. All measurements were performed in one session in the following order—(1) photorefraction without cycloplegia, (2) cycloplegia with cyclopentolate 1 or 0.5 %, (3) cycloplegic autorefractometer, and (4) cycloplegic retinoscopy.

Statistical analysis

Criteria for the accuracy of measurement

We applied the following well-established criteria for the comparison of refraction measurements [5, 18–21]. The difference in the average spherical refractive error (DS) was calculated as photorefraction result minus cycloplegic retinoscopy result, and autorefractometer result minus cycloplegic retinoscopy result. The difference in the average spherical equivalent refractive error (DSE) was calculated as $DSE = (St + 0.5 \times C_t) - (Sc + 0.5 \times C_c)$, where S and C symbolize the spherical and the cylindrical powers. The subscripts 't' (test) and 'c' (comparison) symbolize the instrument being tested (Plusoptix S08) and the control technique (cycloplegic retinoscopy) for comparison. A negative DSE indicates a minus overcorrection of the tested instrument.

The difference between the cylindrical powers (DC) was calculated as $DC = C_t - C_c$.

The weighted cylindrical axis difference (DA) was calculated according to a formula in which the difference between the two cylinder axis (test and comparison, measured in degrees) is weighted with the cylinder power measured with the comparison method. $DA = 2\, C_c \sin(\alpha_t - \alpha_c)$.

The formula allows a comparison of axis values, even when actual cylinder powers are different. C_c is taken as weighting factor, since it is assumed to be more accurate then the cylinder power of the tested instrument [5, 18, 19, 22].

Descriptive statistics included measurements of means, standard deviations and frequencies. Comparisons between measurements were performed using paired two-tailed *t*-tests and correlations with Pearson's correlation analysis. All statistical analyses were performed using SPSS statistical package 19 (SPSS for Windows, Chicago, IL, USA). Statistical significance was defined as $p < 0.05$.

Results

Plusoptix S08, cycloplegic retinoscopy, and cycloplegic autorefractometer measurements for 235 eyes of 118 children (59 female, 59 male) with a mean age of

Table 1 Spherical, spherical equivalent, cylindrical power and axis using Plusoptix S08, cycloplegic retinoscopy, and cycloplegic autorefractometer

	PlusOptix SO8			Cycloplegic retinoscopy			Cycloplegic autorefractometer		
	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
S	−4.75	3.25	0.27 ± 1.64	−3.50	2.75	0.12 ± 1.35	−4.75	3.00	0.16 ± 1.44
C	−4.00	−0.25	−0.81 ± 0.71	−4.25	−0.25	−0.89 ± 0.71	−4.25	−0.25	−0.88 ± 0.72
Axis	0.00	180.00	89.73 ± 61.18	0.00	180.00	92.18 ± 68.39	0.00	180.00	90.86 ± 68.21
SE	−5.38	2.75	−0.05 ± 1.61	−3.88	2.75	−0.15 ± 1.31	−5.38	2.50	−0.12 ± 1.41

Table 2 Correlations of spherical, spherical equivalent, cylindrical power, and axis measurements between cycloplegic retinoscopy and Plusoptix S08 or cycloplegic autorefractometer

		Cycloplegic retinoscopy			
		Spherical	Cylindrical	SE	Axis
PlusOptix SO8	*r*	0.919	0.787	0.881	0.512
	p	0.000*	0.000*	0.000*	0.000*
Cycloplegic autorefractometer	*r*	0.986	0.976	0.969	0.875
	p	0.000*	0.000*	0.000*	0.000*

Spearman correlation * $p < 0.01$

4.9 ± 2.6 years and median age of 5 years (range 1–12) were conducted.

The Plusoptix S08 produced the following mean (±SD) results—spherical 0.27 ± 1.64, cylindrical power −0.81 ± 0.71, axis 89.73 ± 61.18, and spherical equivalent −0.05 ± 1.61. The cycloplegic retinoscopy produced the following mean (±SD) results—spherical 0.12 ± 1.35, cylindrical power −0.89 ± 0.71, axis 92.18 ± 68.39, and spherical equivalent −0.15 ± 1.31. The cycloplegic autorefractometer produced the following mean (±SD) results—spherical 0.16 ± 1.44, cylindrical power −0.88 ± 0.72, axis 90.86 ± 68.21, and spherical equivalent −0.12 ± 1.41 (Table 1).

Spherical ($r = 0.919$; $p < 0.001$), cylindrical power ($r = 0.737$; $p < 0.001$), spherical equivalent ($r = 0.881$; $p < 0.001$), and axis ($r = 0.512$; $p < 0.001$) measurements by Plustopix S08 were strongly correlated with measurements of cycloplegic retinoscopy ($p < 0.01$). Spherical ($r = 0.986$; $p < 0.001$), cylindrical power ($r = 0.976$; $p < 0.001$), spherical equivalent ($r = 0.969$; $p < 0.001$), and axis ($r = 0.875$; $p < 0.001$) measurements by cycloplegic autorefractometer were strongly correlated with cycloplegic retinoscopy measurements ($p < 0.01$) (Table 2).

Frequency distribution scatter plots for spherical, cylindrical power and axis, spherical equivalent measurements by Plusoptix S08 and cycloplegic autorefractometer methods are shown versus cycloplegic retinoscopy measurements in Figs. 1, 2, 3, 4.

For the DS refractive parameter, cycloplegic retinoscopy and Plusoptix S08 methods had an absolute value mean of 0.46 ± 0.34 ($p = 0.006$). Spherical equivalent (SE) measurements between cycloplegic retinoscopy and Plusoptix S08 methods had an absolute value mean of 0.46 ± 0.35 ($p = 0.007$). Cylindrical power measurements for 136 eyes with cylindrical power differences ≤0.25 (absolute value mean 0.20 ± 0.20) showed no difference between Plusoptix S08 and cycloplegic retinoscopy ($p = 0.101$) (Table 3).

There was no difference between cycloplegic retinoscopy and cycloplegic autorefractometry methods with respect to spherical measurements (absolute value mean 0.10 ± 0.29; $p = 0.169$). Furthermore, there was no statistical difference between cycloplegic retinoscopy and cycloplegic autorefractometry methods for spherical equivalent measurements (absolute value mean 0.11 ± 0.30; $p = 0.173$). Cylindrical power measurements for 140 eyes with cylindrical power

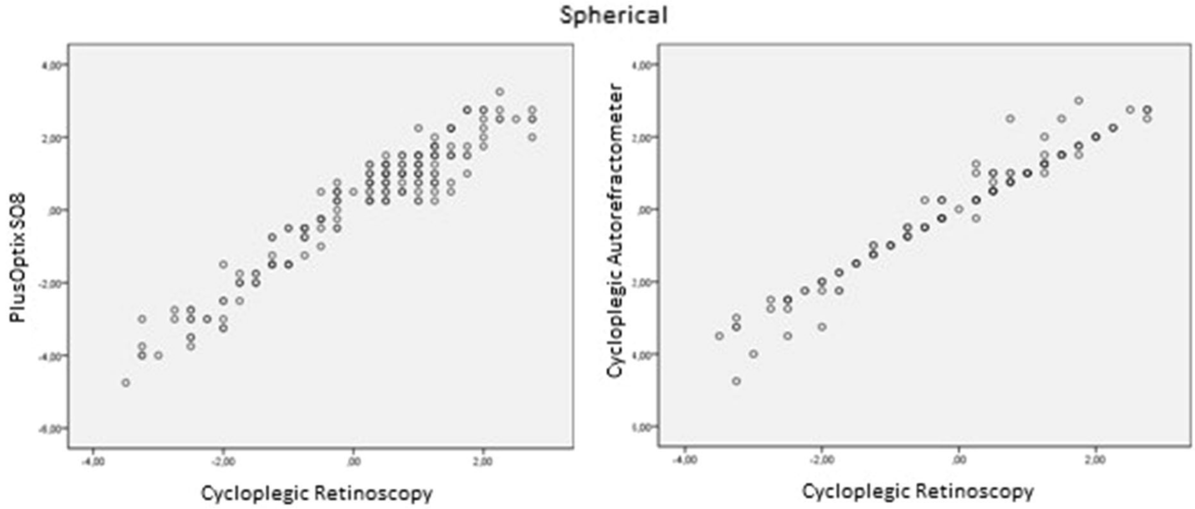

Fig. 1 Frequency distribution *scatter plots* for spherical measurements by Plusoptix S08 and cycloplegic autorefractometer methods are shown versus cycloplegic retinoscopy measurements

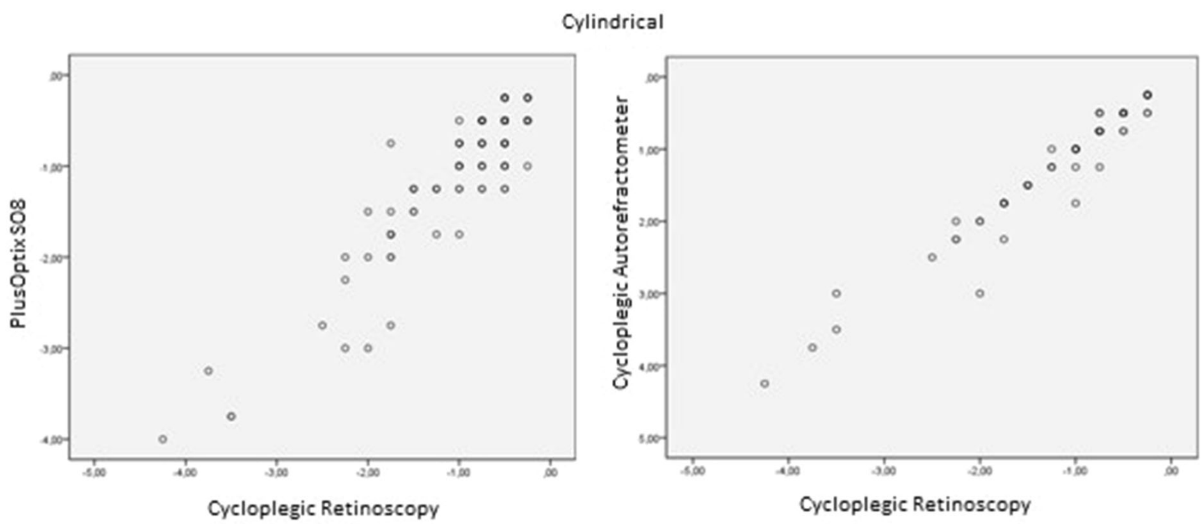

Fig. 2 Frequency distribution *scatter plots* for, cylindrical power measurements by Plusoptix S08 and cycloplegic autorefractometer methods are shown versus cycloplegic retinoscopy measurements

differences ≤0.25 (absolute value mean 0.04 ± 0.14) showed no difference between Plusoptix S08 and cycloplegic retinoscopy ($p = 0.190$) (Table 3).

Sensitivity, specifity, positive predictive values and negative predictive values for cylindrical power measurements ≥0.75 D are shown in (Table 4).

There was no correlation between Plusoptix S08 and cycloplegic retinoscopy with respect to DS ($p = 0.428$), DC ($p = 0.402$) and DSE ($p = 0.583$) differences with age. However, there was a correlation between cycloplegic autorefractometry and cycloplegic retinoscopy with respect to DS ($p = 0.001$), DC ($p = 0.042$) and DSE ($p < 0.01$) differences with age (Table 5).

Discussion

Early detection and treatment of amblyopia yields better outcomes and reduces the prevalence and severity of this disorder in children. The primary purpose of vision screening is for early identification

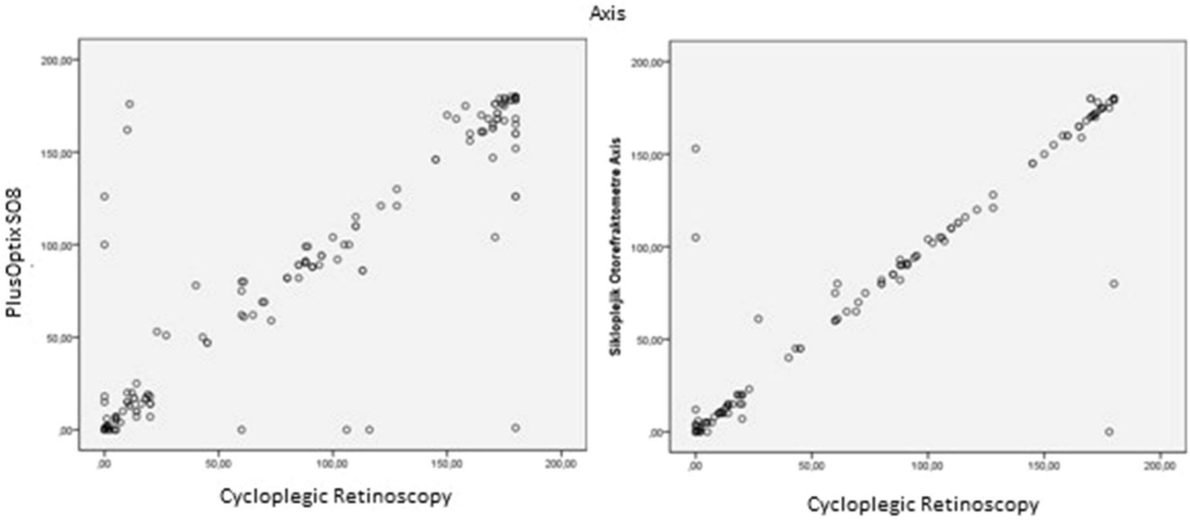

Fig. 3 Frequency distribution *scatter plots* for axis measurements by Plusoptix S08 and cycloplegic autorefractometer methods are shown versus cycloplegic retinoscopy measurements

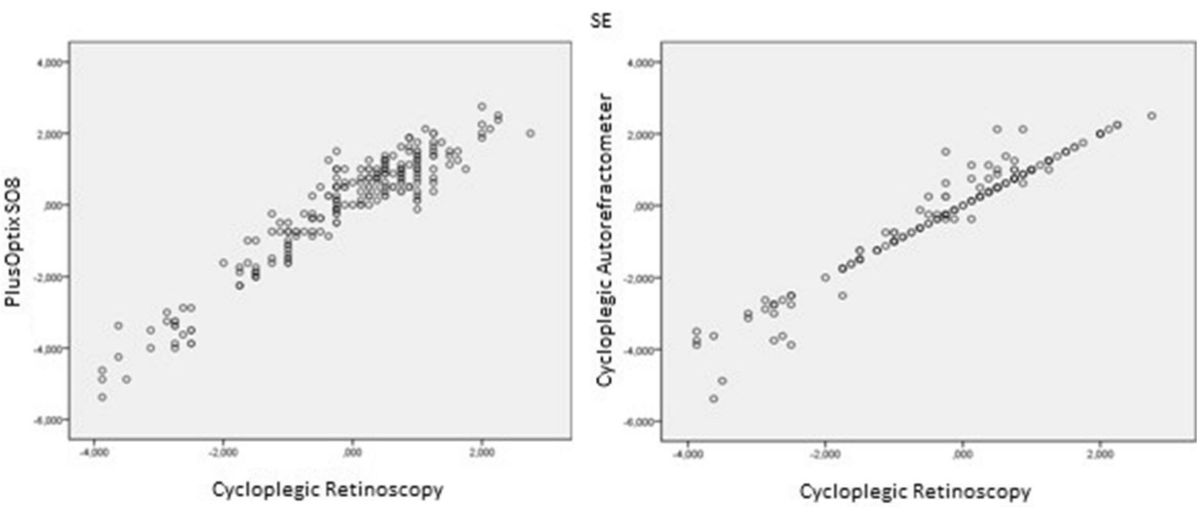

Fig. 4 Frequency distribution *scatter plots* for spherical equivalent measurements by Plusoptix S08 and cycloplegic autorefractometer methods are shown versus cycloplegic retinoscopy measurements

Table 3 Comparisons between DS, DSE, DC, and DA values of both methods

Refractive parameter	Cycloplegic retinoscopy/PlusOptix S08			Cycloplegic retinoscopy/cycloplegic autorefractometer		
	No. of eyes	Mean ± SD	*p*	No. of eyes	Mean ± SD	*p*
DS	235	0.46 ± 0.34	0.006*	235	0.10 ± 0.29	0.169
DSE	235	0.46 ± 0.35	0.007*	235	0.11 ± 0.30	0.173
DC	136	0.20 ± 0.20	0.101	140	0.04 ± 0.14	0.190
DA	136	0.05 ± 1.52		140	0.06 ± 1.37	

Paired samples *t* test * $p < 0.05$

Table 4 Sensitivity, specifity, positive and negative predictive values of both methods

	Cylindrical power on cycloplegic retinoscopy <0.75 D	
	PlusOptix S08 (%)	Cycloplegic autorefractometer (%)
Sensitivity	97.1	100.0
Specificity	83.3	97.9
Positive predictive value	77.3	96.6
Negative predictive value	98.0	100.0

and intervention to reduce the burden of disease. Photoscreening is an easy and very effective way to screen non-verbal children. As new pediatric vision screening methods are developed and become available, it is critically important to compare their validity to that of existing technology.

The value of a screening test is determined by its ability to distinguish a diseased from a normal, non-diseased state. Although an ideal screening test would have 100 % specificity, 100 % sensitivity, and 100 % positive predictive value, there are no vision screening tests with this level of accuracy [23]. Previous studies of Plusoptix S04 by Ugurbas et al. showed that children with intellectual disability benefit from mass screenings and the researchers concluded that Plusoptix S04 is a quick, non-invasive, portable and accurate refraction method that may be useful in special education schools [24]. Matta et al. [16] also showed that the Plusoptix S04 has excellent sensitivity and specificity, is superior to the MTI Photoscreener (UTI, Inc., Cedar Falls, IA, USA), and its computerized, immediate interpretation gives it an additional advantage over other photoscreeners. A study which compared 11 preschool vision screening tests found that at 90 % specificity, the sensitivities of the Retinomax Autorefractor (63 %), SureSight Vision Screener (63 %), Lea Symbols test (61 %), Power Refractor II (54 %), HOT VA test (54 %), Random Dot E stereoacuity (42 %) and Stereo Smile II (44 %) all outperformed the MTI and iScreen photoscreener, which each had 37 % sensitivity [16, 25–29]. In our study, the sensitivities and specifities of Plusoptix S08 for diagnosis of cylindrical power ≤ 0.75 were 97.1 and 83.3 %, whereas those of the autorefractors were 100 and 97.9 %. This high specifity and sensitivity indicate that the Plusoptix S08 device can be used safely and quickly for mass population screening. Ehrt et al. [30] evaluated the photoscreener in 764 subjects to find out which ambliopes are missed without cycloplegy and they estimated that 2–3 cases of amblyopia due to severe refractive errors will be missed when screening a community population of 1,000 children. Most children missed by non-cycloplegic screening were very young and had moderate refractive errors. Therefore, a sensitivity of 80 % is acceptable because most will have mild amblyopia, if any, and can be treated later when it is picked up with visual acuity testing at a later age. Our study has shown that the Plusoptix S08 photoscreener is an effective tool for detecting amblyopia risk factors in young children. Nevertheless, in our study the results are more scattered with Plusoptix S08, this may be the reason why we cannot prescribe spectacles according to Plusoptix alone. Plusoptix should only be used as a screening method especially if we cannot use the much more reliable methods, e.g., crying baby or pupil, where you cannot get retinal reflex with retinoscopy; in these circumstances Plusoptix can be used as a screening method.

There has been little research to determine the best rapid and accurate method of pediatric vision screening in developing countries [31]. School screenings mostly reveal myopia, but not hyperopia so that students at risk for reading problems caused by

Table 5 Correlation between Plusoptix S08, cycloplegic autorefracometer and cycloplegic retinoscopy with respect to DS, DC and DSE differences with age

		Cycloplegic retinoscopy/PlusOptix S08			Cycloplegic retinoscopy/cycloplegic autorefractometer		
		DS	DC	DSE	DS	DC	DSE
Age	r	−0.052	0.055	−0.036	0.216	0.132	0.251
	p	0.428	0.402	0.583	0.001**	0.042*	0.000**

Spearman correlation ** $p < 0.01$, * $p < 0.05$

hyperopia are easyly missed [25, 26]. Vision screeners also detects hyperopia so vision screening programs should feel comfortable switching to this method [16].

Our cycloplegic autorefractometer and retinoscopy results were similar to those previously published, but our Plusoptix S08 results are more hyperopic in some individuals compared to other methods previously published [5, 14, 24]. This shows that the new-generation Plusoptix S08 is not affected much by accommodative power compared to other methods and previous Plusoptix versions.

To our knowledge, this is the only study investigating the effect of age on refractive examinations. In our study, Plusoptix S08 showed that age had no effect on results; thus, this instrument may be used with children of all ages.

In conclusion, visual acuity testing is widely used to detect visual problems but it is largely ineffective due to subjective distance vision examination. This study has shown that cycloplegic autorefractometer and retinoscopy results were similar and Plusoptix S08 is a safe, easy-to-use and reliable screening method of refraction, especially for ophthalmologists unskilled in retinoscopy in accordance with the previous studies [14, 16, 19, 24, 31]. Plusoptix S08 is a useful tool for estimating refraction in patients for whom conventional autorefraction is not an option.

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