Original Article

Accuracy and Repeatability of Refractive Error Measurements by Photorefractometry

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Abstract

Purpose: To determine the accuracy of photorefraction and autorefraction as compared to cycloautorefraction and to detect the repeatability of photorefraction.

Methods: This diagnostic study included the right eyes of 86 children aged 7-12 years. Refractive status was measured using photorefraction (PlusoptiX SO$_4$, GmbH, Nürnberg, Germany) and autorefraction (Topcon RM800, USA) with and without cycloplegia. Photorefraction for each eye was performed three times to assess repeatability.

Results: The overall agreement between photorefraction and cycloautorefraction was over 81% for all refractive errors. Photorefractometry had acceptable sensitivity and specificity for myopia and astigmatism. There was no statistically significant difference considering myopia and astigmatism in all comparisons, while the difference was significant for hyperopia using both amblyogenic ($P = 0.006$) and nonamblyogenic criteria ($P = 0.001$). A myopic shift of 1.21 diopter (D) and 1.58 D occurred with photorefraction in nonamblyogenic and amblyogenic hyperopia, respectively. Using revised cut-off points of + 1.12 D and + 2.6 D instead of + 2.00 D and + 3.50 D improved the sensitivity of photorefractometry to 84.62% and 69.23%, respectively. The repeatability of photorefraction for measurement of myopia, astigmatism and hyperopia was acceptable (intra-cluster correlation [ICC]: 0.98, 0.94 and 0.77, respectively). Autorefraction results were significantly different from cycloautorefraction in hyperopia ($P < 0.0001$), but comparable in myopia and astigmatism. Also, noncycloglegic autorefraction results were similar to photorefraction in this study.

Conclusion: Although photorefraction was accurate for measurement of myopia and astigmatism, its sensitivity for hyperopia was low which could be improved by considering revised cut-off points. Considering cut-off points, photorefraction can be used as a screening method.

Keywords: Accuracy; Autorefraction; Cycloautorefraction; Photorefraction; Repeatability

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INTRODUCTION

Refractive errors have been introduced as the second cause of treatable blindness worldwide.[1] The vision

2020 strategy of the World Health Organization (WHO) has also considered refractive errors as one of the leading causes of treatable blindness along with ocular disorders such as cataract, glaucoma, trachoma and onchocerciasis.[2] Uncorrected refractive errors are the most important factor predisposing to amblyopia among young children but can be controlled using accurate and sensitive screening.[3,4]

Visual acuity (VA) assessment among young children is difficult and unreliable,[5,6] therefore indirect investigation for amblyopia through measurement of refractive errors is advantageous.[7] Cycloplegic refraction is considered as the gold standard for detecting refractive errors,[3] although its application in screening programs entails problems such as being time consuming, requirement for supervision to monitor cycloplegia side effects, and increasing screening expenses and complications. In addition, it requires cooperation by children which is not easy to obtain in some children.[3,5,8,9]

The photorefractometer is a non-contact, infrared video recorder[10] which has been introduced as a useful method for screening of amblyopia especially in preverbal children aged less than 4 years according to the American Association of Pediatric Ophthalmology and Strabismus (AAPOS).[11]

Early photorefractometers were not able to accurately detect astigmatism as compared to available autorefractors, however, modifications have been done to improve their accuracy since they were first introduced in 1974,[12] for instance, cylinder axis is determined in three meridians in newer models to improve assessment of astigmatism.[5] The newer generation of photorefractometer is also equipped with sound stimuli and improved software algorithms allowing faster data processing and statistical analysis, and also providing automatic image recording.[13]

One advantage of photorefractometry is that it can simultaneously detect small angle strabismus,[10] anisometropia, pupillary distance (PD), ptosis and media opacities in both eyes.[14] Furthermore, accommodation might be more relaxed since measurements can be performed at longer working distances (1 m or more) as compared to autorefractors.[15] Photorefractometers produce noises and flashing lights to help children fixate for a few seconds during measurements.[10] The other advantage of photorefractometers over autorefractors is that they are the method of choice for examination of young and uncooperative children and also mentally handicapped patients since subjects do not have to put their head and chin on a chin rest of autorefractometer.[15]

A wide range of sensitivity (63% to 94%) and specificity (62% to 99%) values for photorefractometry have been reported by Schimitzek and Haase.[3] Some studies have concluded that photorefraction has sufficient accuracy and reliability[9,16] and could be considered as an alternative method for widespread school screening programs.[10,11,13] Schimitzek and Lagrèze also believed that photorefractometry is a useful method for ophthalmologists who are not skilled with retinoscopy or when refractive errors cannot be detected by autorefraction.[5] However, Ayse et al[15] found that the PlusoptiX SO$_4$ is not an accurate means to estimate refraction in children.

The current study aimed to determine the accuracy and repeatability of PlusoptiX SO$_4$ as compared to cycloautorefraction as the gold standard. In addition, autorefraction was compared with cycloautorefraction to detect the preferred method for screening refractive errors.

METHODS

This diagnostic study included 86 right eyes of 86 primary school children aged 7-12 years who were examined at the strabismus and pediatric clinic of Imam Hossein Medical Center, Tehran, Iran in 2013 to indicate the accuracy and repeatability of PlusoptiX SO$_4$ (GmbH, Nürnberg, Germany). Children with mental retardation, ocular abnormalities, media opacity, impaired fixation, large angle of strabismus (more than 10 Δ), refractive errors exceeding the measurement range of the photorefractometer (−7.00 diopter [D] to + 5.00D), pupillary abnormalities and severe ptosis in whom photorefractometry could not exactly measure the refractive status, were excluded.

Prior to examination, the parents were interviewed by an optometrist to assess the child's systemic and ocular history, all details of the procedure were explained and written informed consent was obtained from all parents. This study was approved by the ethic committee of Ophthalmic Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Ptosis and nystagmus were detected by direct observation. VA was assessed at distance using Snellen E-chart with 5 letters on each line of a Yang vision tester (SIFI Diagnostic SPA, Via Castellana, Trevise, Italy) in a day light room with or without present glasses. First photorefraction was performed on all children at one meter distance by a trained operator while both eyes were open and repeated 3 times; then, refractive errors were rechecked by an autorefractometer (Topcon RM-8800; Topcon Medical, Oakland, NJ, USA) without cycloplegia. Finally, cycloautorefraction was performed 30-45 min after instillation of cyclopentolate 1% and tropicamide 1% eye drops at 5 min interval, as the gold standard method.

Emmetropia was considered as hyperopia (Sph)<+2.00D, myopia (Sph)>−0.50D and astigmatism <0.75D. Also, nonamblyogenic refractive errors were considered as myopic Sph from -0.50 up to -3.00D and hyperopic Sph from +2.00 up to +3.50D and astigmatism 0.75 up to 1.50D.

Amblyogenic criteria were defined as myopic Sph ≤-3.00D, hyperopia Sph ≥+3.50D and astigmatism ≥1.50D according to AAPOS guidelines.[7]

With-the-rule astigmatism was considered if the axis was 180 ± 30°, while against-the-rule astigmatism was defined as axis within 90 ± 30°; oblique astigmatism was defined when the axis was between 30° and 60° or between 120° and 150°. Weighted axis difference was calculated by the following formula in which the axis difference of tested methods was weighted with the cylindrical (Cyl) power of the basic method in each comparison.[5,10]

Weighted axis difference = 2 × Basic cylinder power sin ($\alpha_2 - \alpha_1$)

α_1 and α_2 were the cylindrical axes of tested and basic methods in degrees, respectively.

Cycloautorefraction was considered as the gold standard during all comparisons, while autorefraction was defined as a basic method when auto and photorefraction were compared. Ocular deviation was evaluated by alternate cover test and the Krimsky method for children with VA ≥20/200 and VA <20/200, respectively. Ocular movements were also assessed in nine cardinal gazes to detect ocular muscle dysfunctions. The examinations were followed by direct ophthalmoscopy and slit lamp examination through a dilated pupil to explore pathological disorders in the anterior or posterior segments. Photorefraction for each child was performed three times by one operator while all conditions were kept stable for determining the repeatability of PlusoptiX SO$_4$.

Statistical Analysis

To present data, mean values, standard deviations, medians and ranges were applied and repeated measure analyses were used to compare the results in multiple measurements. The repeatability of a set of measurements was evaluated using ICC (intra-cluster correlation) and the results of two sets were compared by paired sample *t*-test. To evaluate the diagnostic ability of photorefractometry, we used sensitivity, specificity, positive predictive value (PPV) and negative predictive values (NPV), as well as positive and negative likelihood ratio (LR) and receiver operating characteristic (ROC) curves. The correlations were evaluated using Pearson correlation. All statistical analyses were performed by SPSS software (version 21.0, IBM Co., Chicago, IL, USA).

RESULTS

The accuracy and repeatability of PlusoptiX SO$_4$ were measured in 57 (66.3%) female and 29 (33.7%) male subjects. We compared PlusoptiX SO$_4$ with cycloautorefraction as the gold standard regarding measurement of amblyogenic and nonamblyogenic refractive errors.

Comparison of Photorefraction and Cycloautorefraction

Table 1 compares measurement of nonamblyogenic refractive errors using photorefraction and cycloautorefraction in 86 children. There was no difference between these two methods for measuring myopia and astigmatism, whereas a significant difference was observed in hyperopic measurements. There was 1.2D lower hyperopia (myopic shift) detected with photorefraction due to lack of cycloplegia (*P* = 0.001).

Table 2 compares measurement of amblyogenic refractive errors using photorefraction and cycloautorefraction. There was no statistically significant difference in the measurement of myopia and astigmatism while the difference for hyperopia was statistically significant (1.58 D, *P* = 0.006).

Sensitivity, specificity and other coefficient indices of PlusoptiX SO$_4$ are detailed in Table 3. The sensitivity of photorefraction ranged from 46.15% to 94.74% and its specificity was 88.14% to 100%. Positive and negative predictive values varied from 70.83% to 100% and from 85.25% to 96.1%, respectively. The overall agreement between the two methods was over 81% for

Table 1. Comparison of nonamblyogenic refractive error measurements between photorefraction and cycloautorefraction				
Power (D)	**Spherical power**		**Cylindrical power**	
	H (Sph: +2.00 up to +3.50)	**M (Sph: -0.50 up to -3.00)**	**WTR/ATR (AS: 0.75 up to 1.50)**	**Oblique (AS: 0.75 up to 1.50)**
Cycloautorefraction				
n (%)	26 (30.6)	9 (10.6)	37 (43.5)	4 (4.7)
Mean±SD	3.62±1.49	−1.67±1.1	−1.58±1.19	−0.25±0
Photorefraction				
n (%)	25 (29.1)	8 (9.3)	38 (44.2)	6 (7.0)
Mean±SD	2.95±0.98	−2.09±0.81	−1.99±1.11	−0.29±0.1
Difference				
Value	−1.21	0.17	−0.06	−0.19
95% CI	−1.87-−0.56	−0.24-0.57	−0.22-0.1	−0.57-0.19
P	0.001	0.373	0.436	0.215

There were 50 and 44 eyes with in the range of emmetropia (−0.50D<Sph<+2.00D) and astigmatism (<0.75D), respectively. Sph, sphere; AS, astigmatism; WTR, with-the-rule; ATR, against-the-rule; *P*, probability; CI, confidence interval; SD, standard deviation; D, diopter; *n*, number; SE, spherical equivalent; H, hyperopia; M, myopia

all refractive error criteria. Kappa index was highest for astigmatism in the range of 0.75 up to 1.50D and gradually decreased for myopia; the smallest was calculated for hyperopia.

The largest difference between readings was observed in hyperopic patients as indicated by the largest distance from the cut-off point and the base criteria [Table 3].

The highest correlation between photorefraction and cycloautorefraction was observed for astigmatism (*r* = 0.946) whereas the weakest correlation was related

to spherical equivalent (SE) of hyperopia (*r* = 0.588) according to Pearson correlation [Figure 1].

Receiver operating characteristics (ROC) curves were plotted to obtain the best cut-off points for refractive errors for amblyopia screening. The largest area under the curve belonged to myopia in the range of -0.50 up to -3.00D (*n* = 9) among nonamblyogenic refractive errors which reflects the greater ability of PlusoptiX SO$_4$ in measuring myopia [Figure 2].

Figure 3 shows differences between the two methods in terms of SE, spherical and cylindrical power,

Table 2. Measurement of amblyogenic refractive errors comparing photorefraction and autorefraction with cycloautorefraction				
Power (D)	Spherical power		Cylindrical power	
	Hyperopia (Sph ≥ +3.50)	Myopia (Sph ≤ −3.00)	WTR/ATR (AS ≥1.50)	Oblique (AS ≥1.00)
Cycloautorefraction (1) (gold standard)				
n (%)	29 (16.3)	2 (1.1)	41 (23.0)	9 (5.1)
Mean±SD	4.72±1.2	−4±0	−2.57±1.23	−0.33±0.13
Photorefraction (2)				
n (%)	7 (8.1)	1 (1.2)	23 (26.7)	7 (8.1)
Mean±SD	4.15±0.55	−3.25±0	−2.42±0.98	−0.39±0.2
Difference (1, 2)				
Value	−1.58	-	0.01	−0.19
95% CI	−2.61-−0.54	-	−0.24-0.27	−0.57-0.19
P	0.006	-	0.923	0.215
Autorefraction (3)				
n (%)	11 (6.9)	2 (1.3)	41 (25.6)	8 (5.0)
Mean±SD	4.43±0.9	−4.25±0.35	−2.62±1.26	−0.47±0.16
Difference (1, 3)				
Value	−1.72	−0.25	0.17	0.08
95% CI	−2.08-−1.35	−3.43-2.93	−0.07-0.4	−0.28-0.44
P	0.000	0.500	0.153	0.423
Difference of difference (2, 3)				
Mean±SD	0.15±1.96	-	−0.15±0.77	−0.25±0.43
95% CI	−1.03-1.34	-	0.51-0.20	−1.33-0.83
P	0.782	-	0.37	0.423

Sph, sphere; AS, astigmatism; WTR, with-the-rule; ATR, against-the-rule; *P*, probability; CI, confidence interval; SD, standard deviation; D, diopter; *n*, number
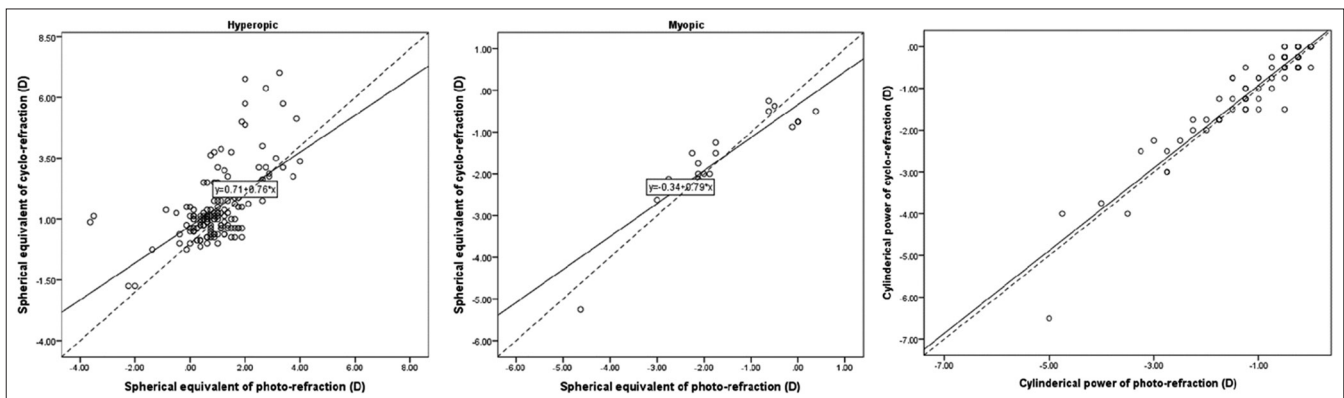

Figure 1. Pearson correlations between photorefraction and cycloautorefraction for hyperopia, myopia and astigmatism (*r*, 0.588; *r*, 0.915 and *r*, 0.946, respectively; *P* < 0.001 for all).

Table 3. Coefficient indices for photorefraction and suggested adjusted cutoff points as compared to cycloautorefraction

Power (D)	Spherical power				Cylindrical power	
	Hyperopia		Myopia		(≥1.5)	(0.75 up to 1.50)
	(≥ +3.50)	(+2.00 up to +3.50)	(≤ −3.00)*	(-0.50 up to -3.00)		
Frequency	13	26	-	9	22	38
Sensitivity (%)	46.15	65.38	-	66.67	81.82	94.74
Specificity (%)	100	88.14	-	97.37	93.65	93.62
Positive predictive value (%)	100	70.83	-	75	81.82	92.31
Negative predictive value (%)	91.14	85.25	-	96.1	93.65	95.65
True positive	6	17	-	6	18	36
True negative	72	52	-	74	59	44
False positive	0	7	-	2	4	3
False negative	7	9	-	3	4	2
Overall agreement	91.76	81.18	-	94.12	90.59	94.12
Prescreening prevalence	15.29	30.59	-	10.59	25.88	44.71
Kappa index	0.59	0.55	-	0.67	0.75	0.88
Cutoff points (D)	2.6	1.12	-	0.375	−1.375	−0.625
Area under the curve	0.928	0.867	-	0.976	0.971	0.954
Sensitivity for cutoff points (%)	69.23	84.62	-	100	81.82	94.74
Specificity for cutoff points (%)	94.44	67.8	-	82.89	93.65	93.62
Positive predictive value (%)	69.23	53.66	-	40.91	81.82	92.31
Negative predictive value (%)	94.44	90.91	-	100	93.65	95.65
True positive	9	22	-	9	18	36
True negative	68	40	-	63	59	44
False positive	4	19	-	13	4	3
False negative	4	4	-	0	4	2
Overall agreement	90.59	72.94	-	84.71	90.59	94.12
Kappa index	0.64	0.45	-	0.51	0.75	0.88

*We only had one patient in this range therefore no statistical analysis was possible. D, diopter
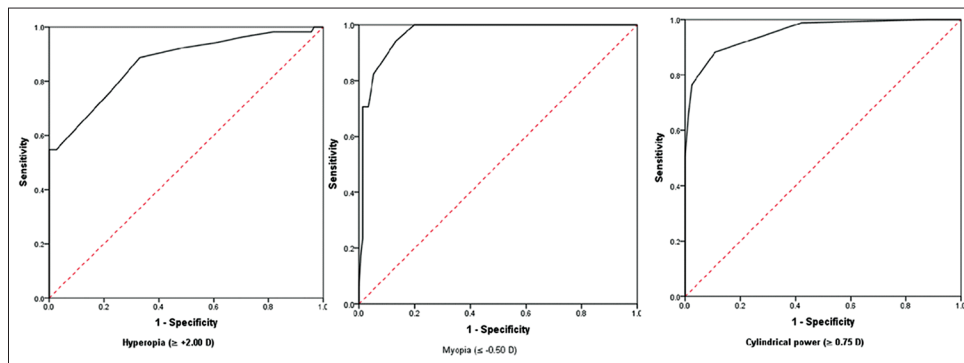

Figure 2. ROC curves for detecting nonamblyogenic refractive errors using photorefraction. Area under curve was 0.867 (95% CI: 0.805-0.930), 0.976 (95% CI: 0.939-0.995) and 0.954 (95% CI: 0.925-0.982) for hyperopia, myopia and cylindrical power, respectively.

and weighted axis. The maximum difference of photorefraction and cycloautorefraction was found for SE of ±1.00D, spherical refractive error of ±1.00D, cylindrical powers in the range of − 0.25D to + 0.50D and weighted axis of plano to +1.00D.

Repeatability of PlusoptiX SO₄

Table 4 shows mean ± SD and median refractive errors based on three measurements in 86 children using PlusoptiX

SO₄. The calculated ICCs showed that PlusoptiX SO₄ was repeatable for measurement of myopia, astigmatism and hyperopia (ICC of 0.98, 0.94 and 0.77, respectively).

Comparison of Photorefraction and Autorefraction

There was no statistically significant difference between autorefraction and photorefraction for measurement of all refractive errors even hyperopia measurements.
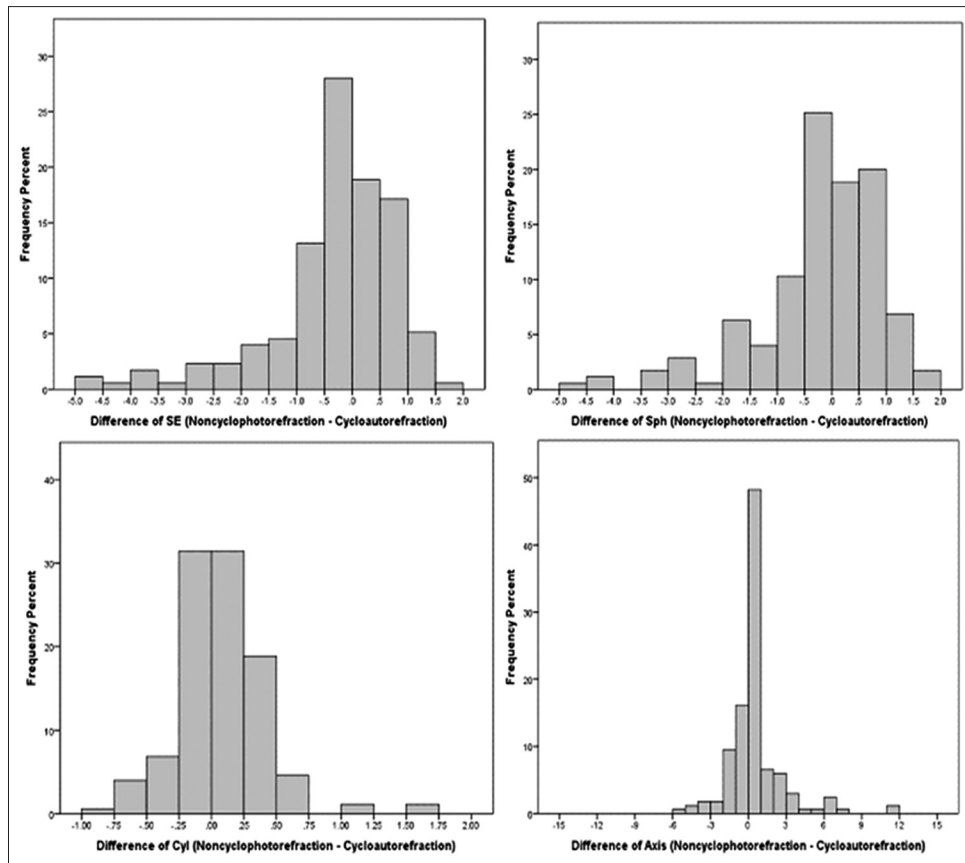
Figure 3. Difference of photorefraction and cycloautorefraction in measuring the spherical equivalent, sphere, cylindrical powers and weighted axis. SE, spherical equivalent; Sph, sphere; Cyl, cylinder.

Table 4. The repeatability of PlusoptiX SO$_4$ for measurement of refractive errors						
Measures	**Myopia (D)**		**Hyperopia (D)**		**Cylinder (D)**	
	Mean±SD	**Median (range)**	**Mean±SD**	**Median (range)**	**Mean±SD**	**Median (range)**
I	−1.12±0.74	−1.25 (−2.25-0)	0.86±0.55	0.75 (0-4.25)	−0.51±0.6	−0.25 (−4.5-0)
II	−1.03±0.72	−1 (−2.25-0)	0.9±0.57	0.75 (0-3.25)	−0.52±0.63	−0.25 (−4.75-0)
III	−0.95±0.84	−1 (−2.5-0.25)	0.94±0.59	0.75 (−0.25-4)	−0.53±0.64	−0.25 (−4.75-0)
ICC	0.981		0.774		0.94	
CV (%)	40		30		37	

ICC, intra-cluster correlation; CV, coefficient of variation; SD, standard deviation; D, diopter

Comparison of Autorefraction and Cycloautorefraction

Table 2 shows a significant difference between autorefraction and cycloautorefraction for measurement of hyperopia among amblyogenic refractive errors; the underestimation by autorefraction was approximately 1.72D ($P < 0.001$).

Figure 4 compares autorefraction and cycloautorefraction. The greatest difference in SE and spherical power was from − 0.50D to plano, and from − 1.00D to plano, respectively and the largest difference in cylindrical power was from plano to +0.25D. The weighted axis of noncycloplegic autorefraction differed from plano to +1.00D as compared to cycloplegic autorefraction measurements.

DISCUSSION

Early visual screening plays an important role in decreasing the prevalence of amblyopia.[10,17,18] It is necessary to apply new methods with sufficient sensitivity and specificity for vision screening.[10] In the current study, three methods including photorefarction and autorefraction (with and without cycloplegia) were used to measure refractive errors. There was no statistically significant difference in myopia and astigmatism measurements in all methods, but hyperopia showed a
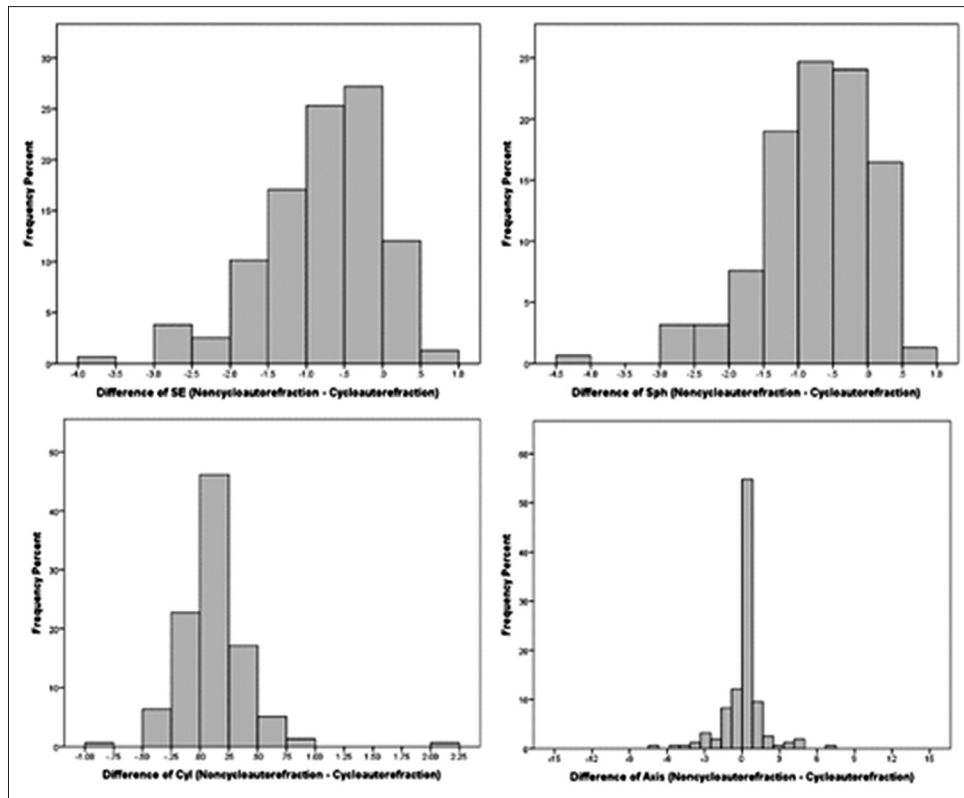
Figure 4. Difference of autorefraction and cycloautorefraction in measuring the spherical equivalent, sphere, cylindrical powers and weighted axis. SE, spherical equivalent; Sph, sphere; Cyl, cylinder.

significant difference between cycloautorefraction and each of photorefraction or autorefraction. By considering cut-off points, photorefraction can be also used as a screening tool [Tables 1 and 2].

We performed photorefraction without cycloplegia based on the manufacturer's recommendation, since induced peripheral aberrations due to dilated pupil makes measurement of astigmatism more difficult and there is a possibility of off-axis refraction.[5,15] Erdurmus et al[8] reported that measuring refractive errors with dilated pupils (>8 mm) is difficult using PlusoptiX CRO3. Ayse et al[15] obtained inaccurate results with PlusoptiX SO$_4$ under cycloplegia especially for cylindrical assessment. Schimitzek and Lagrèze[5] believed that cycloplegia may improve the accuracy of photorefraction for measuring SE, but decreases the accuracy of cylindrical power and axis. Moreover, using cycloplegic drops needs to be supervised for side effects which would increase screening expenses and complications.

To determine the preferable refractive screening method, we simultaneously compared photorefraction, autorefraction with cycloautorefraction (as the gold standard) and found no difference between photorefraction and noncycloautorefraction when comparing each of them with cycloautorefraction, therefore both of these methods can be used for refractive error screening.

The current study showed an overall agreement between photorefraction and cycloautorefraction

ranging from 81.18% to 94.12% using both amblyogenic and non-amblyogenic refractive error criteria [Table 3]; which is in line with the results of other studies reporting 89.7%,[9] 84%[19] and 94%[13] agreements. There was a significant correlation between the two methods for measurement of myopia, and astigmatism [Figures 1 and 2] compatible with our previous study[9] and the report by Erdurmus et al.[8]

A myopic shift was observed with amblyogenic (−1.58 D) and nonamblyogenic (−1.21 D) hyperopia based on photorefractive readings as compared to cycloautorefraction [Tables 1 and 2] which is consistent with other studies.[5,8,9,15,16] This is not an unexpected finding, since noncycloplegic photorefraction at 1 m needs at least 1.00D of accommodation. The myopic shift in our study was close to 1.00D, while Erdurmus et al[8] found the amount to be 0.70D. This discrepancy may be attributed to different age ranges as well as a dissimilar number of hyperopic cases in the two studies. Schaeffel et al[16] found 2.40 D of myopic shift in spite of fogging the eyes using + 3.00D trial lenses. Although Arthur et al[13] found more myopic shift with higher hyperopia, this was not considerable in our study. Schimitzek and Lagrèze[5] also reported − 0.73 ± 1.25 D of myopic shift which was lower than our study due to the wide age range in their study (2-81 years old).

Based on our results, PlusoptiX SO$_4$ had acceptable sensitivity and specificity for measuring myopia and

astigmatism in amblyopia screening [Table 3]; however, it was necessary to modify hyperopic referral criteria to increase the sensitivity of the device for hyperopia. According to ROC curves the referral criteria were set as +1.12D and +2.60D instead of +2.00D and +3.50D for hyperopic patients, respectively. The sensitivity of PlusoptiX SO$_4$ at these revised cutoff points can be improved from 65.38% to 84.62% and from 46.15% to 69.23%, respectively.

We found photorefraction to be an accurate and repeatable method for measurement of refractive errors particularly for myopia and astigmatism [Tables 1-4] which is in agreement with the study by Allen et al[20] Considering the small size of myopic patients in the present study, further investigation in this regard seems necessary.

In summary, the PlusoptiX SO$_4$ photorefractometer and autorefraction accurately measured myopic and cylindrical powers, however, their sensitivity for hyperopia was low as compared to cycloautorefraction as the gold standard. Hyperopic measurements will be improved if adjusted cutoff points are applied. Therefore, photorefraction can be used as a screening method with considering above mentioned revised cut-off points.

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Conflicts of Interest

There are no conflicts of interest.

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