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How to Conduct School Myopia Screening: Comparison Among Myopia Screening Tests and Determination of Associated Cutoffs

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Purpose: To compare the accuracy for various screening tests and their combined uses for myopia screening among children and adolescents and explore age-specific cutoffs.

Design: Cross-sectional study.

Methods: A total of 6017 children and adolescents aged 4 to 15 years participated in the study. Uncorrected visual acuity (UCVA, recorded in decimal notation), cycloplegic and noncycloplegic refraction (NCR), axial length (AL), and corneal curvature radius (CR) examinations were performed. Cycloplegic spherical equivalent ≤ -0.50 D was considered as the gold standard for myopia. Receiver operating characteristic (ROC) curves were drawn to determine optimal cutoffs for all age groups, and sensitivity, specificity, as well as screening prevalence of myopia were calculated.

Results: The overall estimate of myopia prevalence was 31.8% using the gold standard. The sensitivity and specificity of the UCVA alone for the commonly used cutoff (1.0) were 97.7% and 33.1%, respectively. The areas under the ROC curve were optimally estimated to be 0.985 (95% CI, 0.982–0.988) for the combined use of UCVA and NCR tests, and 0.987 (95% CI, 0.983–0.989) for the combined use of AL/CR and NCR tests, with no significant difference ($P = 0.208$). The best cutoffs for UCVA-NCR combinations were UCVA <1.0 and NCR < -0.25 D in 4 to 6 years; UCVA <1.0 and NCR < -0.50 D in 7 to 12 years; UCVA <0.8 and NCR < -0.75 D in 13 to 15 years. If those screening positive were all referred to clinics and corrected with cycloplegic autorefraction data, the relative difference between screening prevalence and the actual prevalence by the gold standard would reduce from 13.2% to 4.7%.

Conclusions: UCVA test alone for detecting myopia demonstrated a poorer accuracy among these tests. The combined use of UCVA and NCR tests and the combined use of AL/CR and NCR tests achieved optimal accuracy for myopia screening. Setting age-specific cutoffs would increase the accuracy, and the prevalence obtained from primary screening should be corrected according to the data of cycloplegic refraction after referral, especially in younger ages.

Key Words: accuracy, children, comparison, cutoff, myopia screening test

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Myopia has become an important public health problem worldwide, with particularly high rates among school-aged children and adolescents.[1–3] The rate of myopia among high school students at graduation can reach as high as 80% to 90% in part of Asian countries. It is predicted that nearly half of the global population will get myopia by 2050, and 9.8% will suffer from high myopia.[1] Being myopic not only imposes an inverse impact on quality of life[3] and future career[4] in children and adolescents, but also causes a health economic burden to the society.[5,6] Myopia screening may facilitate the early detection of myopia and implementation of tailored management, so as to prevent the occurrence and progression of myopia.

Cycloplegic autorefraction is a gold standard for diagnosing myopia in current clinical practice.[7–9] However, since it is time-consuming and could bring temporary side effects including blurred near vision and photophobia, leading to low compliance among children and adolescents, it is not recommended using for large-scale myopia screening. Uncorrected visual acuity (UCVA) test is widely used to screen myopia among children and adolescents worldwide. Although UCVA test is simple and fast, it fails to differentiate refractive types and may lead to a high misdiagnosis rate (calculated as number of the nonmyopic who were wrongly diagnosed as myopic/total number of the nonmyopic).[8,9] To overcome this, noncycloplegic autorefraction and axial length/corneal radius (AL/CR) measurement have been applied in some myopia screenings.[10,11] Previous studies also reported the combined use of these screening tests had a lower misdiagnosis rate.[12,13]

However, the exploration of accuracy comparisons among the abovementioned screening tests and their uses, as well as associated age-specific cutoffs remained limited. This study aimed to examine the accuracy of UCVA, noncycloplegic autorefraction, AL/CR measurements, and their combined uses for myopia screening, and to determine age-specific cutoffs.

METHODS

Participants

Children and adolescents aged 4 to 15 years from 21 kindergartens and schools in Shanghai were randomly selected using a cluster sampling method in 2016. Participants were excluded if they met any of the following criteria: suffering from the allergic constitution, hypertension, or ocular finding that was considered to influence refractive status (for example, corneal scar, strabismus, narrow-angle, glaucoma, or amblyopia). Ethical approval for this study was obtained from the ethics committee of Shanghai General Hospital (No. 2015KY150). The guardians of participants signed informed consent.

Procedures

Tests of visual acuity (VA), cycloplegic and noncycloplegic refraction (CR and NCR), axial length (AL), and corneal radius were performed for all eligible participants. Participants also underwent tonometry and slitlamp tests to help diagnose eye diseases like glaucoma and to determine cycloplegia contraindications. Data on demographic characteristics, such as age, sex, and grade, were also collected. An online information collection system with logic verification (Beijing Gaoshi Information Ltd Co) was used to collect data.

All tests were administered by designated staff who were trained and examined for qualification before the start of this study. Before cycloplegia, VA (uncorrected and with habitual correction if any) was determined using a mounted and illuminated E chart of the Early Treatment Diabetic Retinopathy study (ETDRS) charts (LCD backlit lamp, 400 cd/m^2, WH0701, Guangzhou Xieyi Weishikang) at 4 meters using ambient room lighting. Visual acuity was recorded in decimal notation and was transformed into 5-grade notation for statistical calculation, which was originated from China and included in a Chinese national standard. It could be applied when conducting vision screening in school settings and be equivalently mapped to other notations, including Snellen decimal/fraction and logMAR (Table 1). Its main advantage is that the visual markers are evenly spaced in 5-grade notation, which can be used to do statistical comparison, while the decimal and fraction notation could not be counted and compared directly.[14] Autorefraction was performed using an autorefractor (TOPCON KR8900, Japan). The autorefractor was calibrated before each examination. Three consecutive readings were recorded and averaged as the final figure for each eye. Axial length and corneal radius were measured using an IOL Master (version 5.02, Carl Zeiss Meditec, Oberkochen, Germany). Mean corneal radius was calculated as the mean value derived from readings in horizontal and vertical directions. Cycloplegia was obtained by the following steps. A drop of 0.5% proparacaine hydrochloride was instilled for topical anesthesia and after 15 seconds, a drop of 1% cyclopentolate (Alcon, Fortworth, TX, US) was instilled followed by another drop after 5 minutes. Thirty minutes after the last instillation, pupillary size and response to light were assessed, and cycloplegia deemed complete for pupils larger than 6 mm with an absent reflex to light.[15] An autorefraction test was only performed given complete cycloplegia.

Table 1. Transformation Among 5-Grade Notation, Decimal/Fraction Notation and LogMAR Notation

5-Grade Notation	Decimal Notation	Fraction Notation	LogMAR Notation
3.0	0.01	6/600	2.0
4.0	0.10	6/60	1.0
4.1	0.12	6/48	0.9
4.2	0.16	6/38	0.8
4.3	0.20	6/30	0.7
4.4	0.25	6/24	0.6
4.5	0.32	6/19	0.5
4.6	0.40	6/15	0.4
4.7	0.50	6/12	0.3
4.8	0.63	6/9.5	0.2
4.9	0.80	6/7.5	0.1
5.0	1.00	6/6.0	0.0
5.1	1.25	6/4.8	−0.1
5.2	1.63	6/3.8	−0.20

Statistical Analysis

SPSS (version 18.0) and MedCalc (11.7) were employed to analyze data. Continuous variables were expressed as mean ± standard deviation (SD) if they followed or approximated a normal distribution. A *t* test was used for between-group comparison for continuous variables. For between-group comparison for categorical variables, a chi-square test was used. *P* values less than 0.05 were considered statistically significant.

Spherical equivalent (SE, SE = sphere + 0.5*cylinder) derived from cycloplegic refraction was used as a gold standard for defining myopia, with a cutoff of SE ≤ −0.50 D. Only data for the right eye were analyzed due to a high correlation between 2 eyes. Myopia was classified into mild myopia (−3.00 D < SE ≤ −0.50 D), moderate myopia (−6.00 D < SE ≤ −3.00 D), and high myopia (SE ≤ −6.0 D).[16]

Sensitivity, specificity, the Yonden Index, receiver operating characteristic (ROC) curve, and area under the curve (AUC) were calculated for each of the screening tests and their combinations, and 95% confidence interval (95% CI) for AUC was also reported. For the ROCs of the combined tests, logistic regression was carried out to generate individual prediction probability (pre-value), and then ROCs were drawn with pre-value as diagnostic index. Performance of the screening tests and their combined uses was compared. The optimal age-specific cutoffs and associated myopia prevalence for the screening tests and their combined uses were determined.

RESULTS

Sample Characteristics

From the 6825 participants initially investigated, after the exclusion of 808 participants who were suffered with an ocular finding that was considered to influence refractive status (for example, corneal scar, strabismus, or narrow-angle) or whose data from 1 or both eyes were missing, a total of 6017 participants were finally included in the analysis. Of the analytical sample, the mean age was 9.1 ± 2.9 years and 54.3% were boys (Table 2). Using the gold standard, a total of 1912 (31.8%) eyes were diagnosed with myopia, among which 1245 (20.7%) eyes were diagnosed with mild myopia, 573 (9.5%) moderate myopia, and 94 (1.6%) high myopia. A significant difference of 0.63 D in SE between

Table 2. Sample Characteristics

Variable	n (%)
Age groups, y	
4–6	1572 (26.1)
7–12	3727 (62.0)
13–15	718 (11.9)
Sex	
Boys	3270 (54.3)
Girls	2747 (45.7)
Myopia	1912 (31.8)
Mild myopia	1245 (20.7)
moderate myopia	573 (9.5)
High myopia	94 (1.6)
Non-myopia	4105 (68.2)
UCVA (5-grade notation), mean ± SD	4.8 ± 0.3
Precycloplegia SE (D), mean ± SD	−0.79 ± 1.79
Postcycloplegia SE (D), mean ± SD	−0.16 ± 2.02
Axial length (mm), mean ± SD	23.43 ± 1.20
Mean corneal radius (mm), mean ± SD	7.85 ± 0.26
AL/CR, mean ± SD	2.99 ± 0.14

AL/CR indicates axial length/corneal radius ratio; D, diopter; SD, standard deviation; SE, spherical equivalent; UCVA, uncorrected visual acuity.

precycloplegia and postcycloplegia was observed ($P < 0.001$, obtained from the paired t test).

Comparison of ROCs Among Screening Tests

The ROCs for the screening tests and their combinations were presented in Figure 1. The AUCs were optimally estimated to be 0.985 (95% CI, 0.982–0.988) for the combined use of UCVA and NCR tests, and 0.987 (95% CI, 0.983–0.989) for the combined use of AL/CR and NCR tests, with no significant difference ($P = 0.208$). The AUCs for NCR, the combined use of UCVA and AL/CR, AL/CR, and UCVA tests were 0.982, 0.977, 0.954, and 0.928, respectively. A significant difference in the AUCs among these 4 was observed ($P < 0.05$).

Optimal Age-Specific Cutoffs and Accuracy

Age-specific cutoffs and accuracy for screening myopia using UCVA alone are shown in Table 3. When the cutoff of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0) was used for the total population, the sensitivity was 97.7% and the specificity was only 33.1%. The optimal cutoff of using UCVA alone for screening myopia was 0.63 (5-grade equivalent: 4.8; fraction

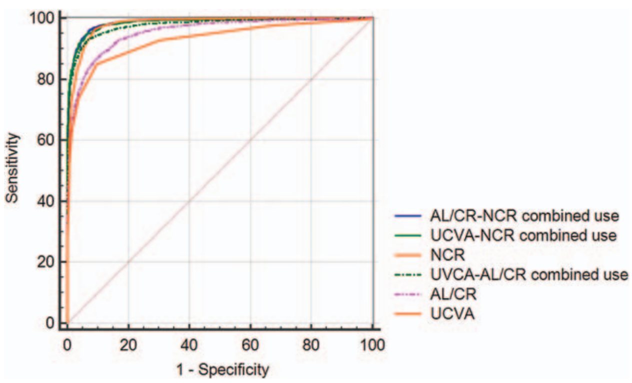

Figure 1. Receiver operating characteristic curves of different screening tests and their combinations. AL/CR indicates axial length/corneal radius ratio; NCR, noncycloplegic autorefraction; UCVA, uncorrected visual acuity.

Table 3. Age-Specific Cutoffs and Accuracy for Screening Myopia Using UCVA

Age Groups	UCVA Cutoffs (Decimal Notation)	Sensitivity (%)	Specificity (%)	Yonden Index
4–6 y	<0.63*	67.3	84.7	0.520
	<0.80	86.5	51.2	0.377
	<1.00	96.2	10.1	0.063
7–12 y	<0.63	82.6	93.5	0.761
	<0.80	91.7	80.3	0.720
	<1.00	97.7	45.7	0.434
13–15 y	<0.63	91.8	91.7	0.835
	<0.80	95.6	85.4	0.810
	<1.00	97.7	61.1	0.588
Overall	<0.63	84.9	90.2	0.751
	<0.80	92.7	69.7	0.624
	<1.00	97.7	33.1	0.308

*UCVA indicates uncorrected visual acuity, recorded in decimal notation. $VA_{5\text{-grade}} = 5 - \lg(1/VA_{decimal})$.

1.00 in decimal equivalent = 5.0 in 5-grade notation = 6/6.0 in fraction notation = 0.0 in logMAR notation.

0.80 in decimal equivalent = 4.9 in 5-grade notation = 6/7.5 in fraction notation = 0.1 in logMAR notation.

0.63 in decimal equivalent = 4.8 in 5-grade notation = 6/9.5 in fraction notation = 0.2 in logMAR notation.

equivalent: 6/9.5; logMAR equivalent: 0.2), and the overall sensitivity was 84.9%, while the specificity was 90.2%. Among children aged 4 to 6 years, the sensitivity was only 67.3% for cutoff of 0.63 (5-grade equivalent: 4.8; fraction equivalent: 6/9.5; logMAR equivalent: 0.2), and the specificity was only 10.1% for the cutoff of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0). With the increase of the cutoffs, the sensitivity increased and the specificity decreased. When using NCR alone for screening myopia, the optimal cutoff was −0.75 D, and the overall sensitivity was 96.6%, while the specificity was 91.0%. The optimal cutoffs of NCR for 4 to 6 years, 7 to 12 years, and 13 to 15 years were −0.50 D, −0.75 D, and −1.50 D respectively. When AL/CR alone was used for screening myopia, the optimal cutoff was 3.02, and the overall sensitivity was 87.2%, while the specificity was 90.1%. The optimal cutoffs of AL/CR for 4 to 6 years, 7 to 12 years, and 13 to 15 years were 2.96, 3.02, and 3.07, respectively.

The combined use of UCVA test with a cutoff of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0) and NCR test with a cutoff of −0.50 D achieved the highest accuracy than any other cutoffs, resulting in a sensitivity of 95.7%, a specificity of 92.6%, and a Yonden index of 0.883. Age-specific cutoffs and accuracy for combined use of UCVA and NCR tests were presented in Table 4. The combined use of UCVA test with a cutoff of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0) and NCR test with a cutoff of −0.25 D achieved optimal accuracy for children aged 4 to 6 years, resulting in a sensitivity of 94.2% and a specificity of 89.5%. The combined use of UCVA test with a cutoff of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0) and NCR test with a cutoff of −0.5 D achieved optimal accuracy for children aged 7 to 12 years, resulting in a sensitivity of 95.3% and a specificity of 92.5%. The combined use of UCVA test with a cutoff of 0.80 (5-grade equivalent: 4.9; fraction equivalent: 6/7.5; logMAR equivalent: 0.1) and the NCR test with a cutoff of −0.75 D achieved optimal accuracy for children

Table 4. Age-Specific Cutoffs and Accuracy for the Combined Use of UCVA and NCR Tests

Age Group	UCVA	NCR	Sensitivity (%)	Specificity (%)	Yonden Index
4–6 y					
	<1.00	<−0.25 D	94.2	89.5	0.837*
	<1.00	<−0.50 D	86.5	93.8	0.803
	<1.00	<−0.75 D	65.4	96.5	0.619
	<1.00	<−1.50 D	25.0	99.4	0.244
	<0.80	<−0.25 D	86.5	92.9	0.794
	<0.80	<−0.50 D	78.8	96.0	0.748
	<0.80	<−0.75 D	59.6	98.0	0.576
	<0.80	<−1.50 D	25.0	99.7	0.247
	<0.63	<−0.25 D	67.3	97.3	0.646
	<0.63	<−0.50 D	65.4	98.2	0.636
	<0.63	<−0.75 D	53.8	99.1	0.529
	<0.63	<−1.50 D	25.0	99.9	0.249
7–12 y					
	<1.00	<−0.25 D	97.4	85.6	0.830
	<1.00	<−0.50 D	95.3	92.5	0.878*
	<1.00	<−0.75 D	89.4	96.0	0.854
	<1.00	<−1.50 D	67.3	99.1	0.664
	<0.80	<−0.25 D	91.5	94.4	0.859
	<0.80	<−0.50 D	90.3	96.8	0.871
	<0.80	<−0.75 D	86.0	98.4	0.844
	<0.80	<−1.50 D	66.7	99.7	0.664
	<0.63	<−0.25 D	82.6	98.3	0.809
	<0.63	<−0.50 D	81.9	99.0	0.809
	<0.63	<−0.75 D	79.5	99.1	0.786
	<0.63	<−1.50 D	64.6	99.9	0.645
13–15 y					
	<1.00	<−0.25 D	97.7	75.7	0.734
	<1.00	<−0.50 D	97.2	81.3	0.785
	<1.00	<−0.75 D	97.0	87.5	0.845
	<1.00	<−1.50 D	86.2	96.5	0.827
	<0.80	<−0.25 D	95.6	90.3	0.859
	<0.80	<−0.50 D	95.3	92.4	0.877
	<0.80	<−0.75 D	95.1	95.8	0.909 *
	<0.80	<−1.50 D	85.7	99.3	0.850
	<0.63	<−0.25 D	91.8	95.1	0.869
	<0.63	<−0.50 D	91.6	96.5	0.881
	<0.63	<−0.75 D	91.5	97.2	0.887
	<0.63	<−1.50 D	84.7	99.3	0.840
Overall					
	<1.00	<−0.25 D	97.4	86.7	0.841
	<1.00	<−0.50 D	95.7	92.6	0.883 *
	<1.00	<−0.75 D	91.1	95.9	0.870
	<1.00	<−1.50 D	71.9	99.1	0.710
	<0.80	<−0.25 D	92.6	93.7	0.863
	<0.80	<−0.50 D	91.5	96.3	0.878
	<0.80	<−0.75 D	88.0	98.2	0.862
	<0.80	<−1.50 D	71.3	99.7	0.710
	<0.63	<−0.25 D	84.9	97.8	0.827
	<0.63	<−0.50 D	84.4	98.6	0.830
	<0.63	<−0.75 D	82.4	99.4	0.818
	<0.63	<−1.50 D	69.6	99.9	0.695

D indicates diopter; NCR, noncycloplegic autorefraction; UCVA, uncorrected visual acuity, recorded in decimal notation.

$VA_{5\text{-grade}} = 5 - \lg(1/VA_{decimal})$.

1.00 in decimal equivalent = 5.0 in 5-grade notation = 6/6.0 in fraction notation = 0.0 in logMAR notation.

0.80 in decimal equivalent = 4.9 in 5-grade notation = 6/7.5 in fraction notation = 0.1 in logMAR notation.

0.63 in decimal equivalent = 4.8 in 5-grade notation = 6/9.5 in fraction notation = 0.2 in logMAR notation.

*Indicates the highest accuracy.

aged 13 to 15 years, resulting in a sensitivity of 95.1% and a specificity of 95.8%. The combination of AL/CR test with a cutoff of 2.95 and NCR test with a cutoff of −0.50 D achieved highest accuracy than any other cutoffs, resulting in a sensitivity of 94.0% and a specificity of 95.0%. The combination of UCVA test with a cutoff of 0.80 (5-grade equivalent: 4.9; fraction equivalent: 6/7.5; logMAR equivalent: 0.1) and AL/CR test with a cutoff of 2.96 achieved highest accuracy than any other cutoffs, resulting in a sensitivity of 94.5% and a specificity of 89.7%.

Classification results for the combined use of UCVA test with a cutoff of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0) and NCR test with a cutoff of

Table 5. Cross Table for the Accuracy of the Combined Use of UCVA and NCR Tests for Myopia Screening

		Cycloplegic Autorefraction Test (Gold Standard)		
		Positive	Negative	Overall
Combined use of UCVA and NCR tests	Positive	1829	304	2133
	Negative	83	3801	3884
	Overall	1912	4105	6017

NCR indicates noncycloplegic autorefraction; UCVA, uncorrected visual acuity.

−0.50 D for myopia screening were presented in Table 5. Of the 1912 (31.8%) myopic children diagnosed using the gold standard, 83 (4.3%) were left undiagnosed with myopia using the combined tests, with a mean age of 10.5 ± 2.7 years. Of the misclassified children, the mean UCVA was 0.80; the mean SE was -0.90 ± 1.04 D; 80 (96.4%) were mildly myopic. Of the 4104 nonmyopic children according to the gold standard, 304 (7.4%) were misdiagnosed with myopia using the combined tests, with a mean age of 8.6 ± 2.8 years. Of the misdiagnosed children, the mean UCVA was 0.63; the mean SE was 0.48 ± 0.74 D; 288 (94.7%) were in normal refraction (-0.50 D $<$ SE $<$ $+2.00$ D).

Comparison of Prevalence Estimates by Different Screening Tests

Table 6 presented the estimates of myopia prevalence by these screening tests. Using the gold standard for myopia screening, the estimates of the overall myopia prevalence were 31.8% for the whole population, and the prevalence for children aged 4 to 6 years, 7 to 12 years, and 13 to 15 years were 3.3%, 24.5%, and 79.4%, respectively. Using UCVA test, the overall estimate was 76.7%. Using the other screening tests, the estimates varied from 32.3% to 36.9%, which differed by 0.5% to 5.1% from that derived from the gold standard. Supposing all the students who were screened positive were transferred for cycloplegic refraction and the prevalence was corrected according to the cycloplegic data, the difference between screening prevalence and actual prevalence (by gold standard) would be narrowed, with the relative difference between screening prevalence and the actual prevalence being reduced from 13.2% to 4.7%.

DISCUSSION

The current study examined the accuracy of UCVA, noncycloplegic autorefraction, AL/CR measurements, and their combined uses for myopia screening, as well as determined age-specific cutoffs. The results demonstrated that the UCVA test alone for detecting myopia demonstrated a poorer accuracy among these tests. The combined use of UCVA and NCR tests and the combined use of AL/CR and NCR tests achieved optimal accuracy for myopia screening. Setting age-specific cutoffs would increase the accuracy, and the prevalence obtained from primary screening should be corrected according to the data of cycloplegic refraction after referral, especially in lower ages.

The AUCs were optimally estimated to be 0.985 for the combined use of UCVA and NCR tests, and 0.987 for the combined use of AL/CR and NCR tests, with no significant difference. The Yonden index for the combined use of UCVA < 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0) and NCR < -0.50 D was optimally estimated to be 0.883, which was higher than those derived using UCVA or NCR test alone. This improvement is similar to that reported in previous studies.[12,13] The Yonden index was further

Table 6. Myopia Prevalence Estimated by Different Screening Tests (%)

Screening Test (Cutoff)	4–6 y (n = 1572)	7–12 y (n = 3727)	13–15 y (n = 718)	Overall (%)	Overall Difference§
Cycloplegic autorefraction (≤ −0.50 D)	3.3	34.5	79.9	31.8	—
UCVA (<1.0)	90.1	69.3	85.9	76.7	44.9
UCVA*	50.1	44.5	79.4	50.1	18.3
Corrected prevalence by UCVA†	2.9	31.6	76.5	29.5	−2.3
NCR (≤−0.75 D)	7.8	40.0	84.4	36.9	5.1
NCR*	12.5	40.0	73.4	36.8	5.0
Corrected prevalence by NCR†	3.1	33.2	72.3	30.0	−1.8
AL/CR (>3.02)	2.7	37.0	79.9	33.2	1.4
AL/CR*	9.9	37.0	70.1	33.9	2.1
Corrected prevalence by AL/CR†	2.4	28.9	68.8	26.7	−5.1
UCVA-NCR combined use (VA < 1.0 and SE < −0.5 D)	8.9	37.8	81.5	35.4	3.6
UCVA-NCR combined use*	13.2	37.8	76.9	36.0	4.2
Corrected prevalence by UCVA-NCR combined use†	3.1	32.9	76.0	30.3	−1.5
AL/CR-NCR combined use (AL/CR > 2.95 and SE < −0.5 D)	3.4	38.0	82.6	34.3	2.5
Corrected prevalence by AL/CR-NCR combined use†	2.3	32.7	78.3	30.2	−1.6
UCVA-AL/CR combination (VA < 0.80 and AL/CR > 2.96)	5.5	35.0	76.7	32.3	0.5
Corrected prevalence by UCVA-AL/CR combined use†	2.2	30.7	75.1	28.5	−3.3

AL/CR indicates axial length/corneal radius ratio; D, diopter; NCR, noncycloplegic autorefraction; SE, spherical equivalent; UCVA, uncorrected visual acuity; VA, visual acuity.

*Age-specific cutoffs were used when determining myopia.

†Those who were screened positive according to age-specific cutoffs were transferred for cycloplegic autorefraction.

§Overall difference between screening prevalence and actual prevalence (by gold standard).

improved to 0.890 when applying the combined use of AL/CR and NCR tests. In clinical practice, autorefractor is more widely adopted than axial length measurement devices. Furthermore, nonspecialist personnel can be trained to operate an autorefractor successfully. The data generated from autorefractors in different brands and models are comparable.[11] Axial length measurement has, so far, only been applied into practice in leading ophthalmology departments and requires a relatively higher level of specialty for operators. Also, a secondary calculation is required when performing AL/CR test. Hence, in consideration of nearly identical accuracy, the combined use of UCVA and NCR tests is more feasible in the practice of myopia screening. However, axial length still has a more important value in longitudinal management. It is a feasible alternative screening program in the future when the measurement technology is more accessible.

Our study suggested that age-specific screening tests and associated cutoffs should be applied in myopia screening among children and adolescents. The body of children and adolescents is still growing and developing, including the eyeball and the regulatory power of intraocular muscles.[17] Therefore, the physiological values of refractive parameters will be different at the corresponding development stages of different ages. For example, the VA of children aged 4 to 6 years will not be fully matured and they may not reach an acuity of 1.0 (5-grade equivalent: 5.0; fraction equivalent: 6/6.0; logMAR equivalent: 0.0), thus the cutoff of VA<1.0 should not be set as a unified standard for all ages.[18] The noncycloplegic refraction would differ from the real refractive state, as a result of the strong accommodation force of ocular muscle among children and adolescents, which may deviate toward myopia.[19] A previous study indicated that the accommodation force of ocular muscle increased as age decreased, which could result in a large difference in SEs between precycloplegia and postcycloplegia in younger ages. This difference could change from −0.95 D in children aged 4 years to −0.33 D in children aged 15 years.[18] Based on this finding, it is also advocated that a cycloplegic autorefraction test should be performed for kindergarten children and lower grades of primary school children as far as possible.

The aim of the screening test is early detection and intervention. Therefore, misclassification associated with the screening tests is an important aspect to evaluate the accuracy of the screening. The undiagnosed rate was 4.3% in our study when performing the combined use of UCVA and NCR tests. Most of the undiagnosed children were mildly myopic with a mean VA of 0.80 (5-grade equivalent: 4.9; fraction equivalent: 6/7.5; logMAR equivalent: 0.1) and a mean cycloplegic SE of −0.90 D. Being undiagnosed could impose an adverse impact on the control of myopia progression among this population. However, most of those undiagnosed children are all new onset myopia with adequate visual acuity, there should not be a necessity that a pair of glasses be prescribed and the impact on their daily life could be ignored. The misdiagnosed rate in our study was 7.4% when performing the combined use of UCVA and NCR tests, resulting in a total of 304 nonmyopic children misclassified as being myopic. The misclassification may bring about medical resource wasting because a referral is implemented after the screening. However, mean SE refractive error from NCR test was less than +0.50 D and the mean VA was 0.63 (5-grade equivalent: 4.8; fraction equivalent: 6/9.5; logMAR equivalent: 0.2) among the misclassified children, which indicates that this population should be considered as the population at higher risk and that early warning could contribute to awareness and prevention enhancement. The choice of sensitivity and specificity values and associated cutoffs should be made according to the level of screening resource and screening aims, instead of considering the Yonden index as the only indicator of accuracy.[20] If screening resource is adequate and it is aimed that nonmyopic population who are in premyopic stage (SE close to −0.50 D) should be identified and administered interventions, screening sensitivity is supposed to be assured when determining cutoffs. Besides, improvements in screening techniques are expected in the future to decrease the false-negative and false-positive rates.

Additionally, the prevalence estimated by the tests mentioned in this study had a difference of under 6% from the gold standard among children aged 4 to 15 years, except for UCVA test whose difference was 18.3% despite that age-specific cutoffs were used. The combination of UCVA and NCR tests will certainly overestimate the prevalence of myopia, especially in younger children. The estimate of myopic prevalence derived using the combined use of UCVA and AL/CR tests was the closest to that derived using the gold standard, which indicates that AL/CR test could have added value in myopia prevalence assessment. It should be acknowledged that the different estimates of myopia prevalence derived using the screening tests can only measure the deviation from the gold standard but not as an evaluation of the accuracy among the screening tests. If the screening positive students are referred and cycloplegic refraction is carried out, and the myopia rate in the primary screening is corrected, the false-positive cases will be excluded so that the screening myopia rate is closer to the myopia rate measured by the gold standard, with the relative error decreased from 13.2% to 4.7%. However, it is still necessary to conduct smaller studies of statistically valid samples using cycloplegia to obtain the actual prevalence data.

Limitations should be acknowledged when interpreting the results. Firstly, only cross-sectional data were included, and the sensitivity of these screening tests to longitudinal progression changes was not analyzed. Secondly, the screening methods and indicators included in the comparison were still not comprehensive. Besides, the age distribution of the sample was uneven, which might draw a certain bias to the determination of the overall cutoff. Finally, the comparison of these tests in the study could provide information for myopia screening among both Asians and non-Asians, but when it comes to age-specific cutoffs, it should be further validated in non-Asians for its applicability.

In this study, accuracy, cutoffs, and feasibility for the screening tests were systematically analyzed and discussed, which could provide references for the practice of myopia screening. However, our findings are expected to be continuously validated and improved in practice, and new techniques including artificial intelligence and machine learning algorithms remain needed to facilitate myopia screening for continuously increasing accuracy and feasibility. Myopia screening aims for early identification and early intervention, which means how to improve referral and intervention rates after screening plays a vital role in myopia prevention and control.

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