Comparison of Preschool Vision Screening Methods in a Population with a High Prevalence of Astigmatism

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Purpose. To compare the effectiveness of four methods of screening 3- to 5-year-old children for astigmatism high enough to require spectacle correction.

Methods. Lea Symbols Visual Acuity Screening (LSVAS), MTI Photoscreening (MTIPS), Nidek KM-500 Keratometry Screening (KERS), and Retinomax K-Plus Noncycloplegic Autorefraction Screening (NCARS) were attempted on 379 preschool children who are members of a Native American tribe having a high prevalence of astigmatism that is primarily corneal in origin. The need for spectacle correction was determined by cycloplegic refraction. Receiver Operating Characteristic (ROC) curves were fit, confidence intervals were determined, and area under the curves was compared.

Results. Astigmatism ≥ 1.00 D was present in the right eye of 47.5% and in the left eye of 48.0% of children. Spectacles were prescribed for children < 48 months of age who had cylinder ≥ 2.00 D and children ≥ 48 months who had cylinder ≥ 1.50 D, with the result that 33% of subjects required spectacles. Area under the ROC curve was 0.98 for NCARS, 0.92 for KERS, 0.78 for MTIPS, and 0.70 for LSVAS, and each of these values differed significantly from the other three (all $P < 0.007$). Testability was significantly higher for NCARS (99.5%) and KERS (99.7%) than for MTIPS (93.5%) and LSVAS (92.0%).

Conclusions. In a population that included many children with astigmatism, objective, fully automated screening methods (NCARS and KERS) were superior to both visual acuity screening and photoscreening with subjective interpretation in identifying children who had astigmatism requiring spectacle correction. (*Invest Ophthalmol Vis Sci.* 2001;42:917–924)

Recommendations for vision screening of preschool children emphasize detection of decreased visual acuity and ocular misalignment.[1–5] However, for the preschool-aged child, there is often difficulty in differentiating the child who *cannot see well* (resulting in a true-positive screening examination) from the child who *does not perform well* in visual acuity testing, despite being free of visual disability (false-positive screening results). Consequently, there has been an effort to develop techniques that permit detection of amblyogenic conditions such as strabismus and refractive error but that do not require the level of cooperation that is needed to test visual acuity in a preschool-aged child.

The present article reports the results of a study designed to identify optimal methods of screening a specific population of preschool-aged children: Native American children who are members of a tribe known to have a high prevalence of astigmatism that is primarily corneal in origin.[6–9] Four methods were compared: (1) visual acuity screening with the Lea Symbols (LSVAS) distance visual acuity test (Precision Vision, LaSalle, IL); (2) photoscreening using the MTI Photoscreener (MTIPS; Medical Technology, Inc., Lancaster, PA); (3) screening for corneal astigmatism using the Nidek KM-500 auto keratometer (KERS; Marco Ophthalmic, Inc., Jacksonville, FL); and (4) screening for refractive astigmatism using the Retinomax K-plus (Rmax K+) autorefractor/autokeratometer (Nikon, Inc., Melville, NY). Screening results were compared with measurements of astigmatism obtained during cycloplegic refraction conducted as part of a complete eye examination.

Methods

Subjects

Data were collected as part of a study of astigmatism and amblyopia among Native American children,[10] in which Head Start enrollees underwent vision screening and complete eye examinations, including cycloplegic refraction. The present analysis is based on data from 379 children: 248 tested in Fall 1997 and 131 tested in Fall 1998. Data from 31 children tested in 1997 and 107 children tested in 1998 were excluded for the following reasons: (a) age > 5 years ($n = 3$) or <3 years ($n = 15$) on September 1; (b) identification by Head Start as "special needs" ($n = 21$), because the ability of these children to cooperate for screening procedures was likely to be different from that of most 3- to 5-year-olds; (c) presence of ocular pathology: nystagmus ($n = 1$), iris coloboma ($n = 1$), or posterior lenticonus ($n = 1$); and (d) failure to provide cycloplegic refraction data, because of lack of cooperation ($n = 2$) or parental refusal ($n = 1$). Data were also excluded from 93 children tested in 1998 who were in their second year of Head Start and who had provided data for this study in their first Head Start year (1997). Manifest strabismus (constant or poorly controlled esotropia, exotropia, or hypertropia) was not seen in any child whose data were included in the analysis. Three children arrived at the test session wearing glasses. Their visual acuity was tested with correction, but the data were not included in analyses of visual acuity results.

The gender and age distribution of subjects at the time of testing is shown in Table 1. Although no children were 5 years of age at enrollment (September), 15 were age 5 by the time of testing.

Procedures

The research followed the tenets of the Declaration of Helsinki, the protocol was approved by the University of Arizona Institutional Review Board, and parental informed consent was obtained.

Testing was performed at seven Head Start or community centers. Each child was tested with the four screening procedures before receiving a comprehensive eye examination and cycloplegic refraction. The order in which screening procedures were conducted varied from child to child and depended on which tester was available when the child completed check-in and when the child completed each subsequent screening test. Screening procedures were conducted by trained testers whose experience in vision screening ranged from 0 to >20 years and whose education ranged from high school diploma to postgraduate degree.

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Supported by Grant EY11155 from the National Eye Institute, National Institutes of Health, Bethesda, Maryland.

Submitted for publication September 5, 2000; revised December 11, 2000; accepted December 20, 2000.

Commercial relationships policy: N.

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TABLE 1. Age of Children at the Time of Testing

	36–47 Months	48–59 Months	60–63 Months	Total
Female	94	101	7	202 (53.3)
Male	80	89	8	177 (46.7)
Total	174 (45.9)	190 (50.1)	15 (4.0)	379

Values in parentheses are percentages.

Visual Acuity Screening (LSVAS). Monocular visual acuity was measured at a distance of 3 m, using a 62 × 65 cm, rear-illuminated Lea Symbols logMAR distance acuity chart. The chart contains 15 lines, with five symbols per line, progressing in logarithmic steps from 6/60 (20/200) to 6/2.4 (20/8). Acuity testers were masked to the results of the other screening procedures.

A binocular pretest was conducted in which the child was shown the four test symbols (square, house, circle, apple) and was required to identify each symbol verbally or by matching. The left eye was then occluded with 5-cm-wide translucent paper tape. Testing began with the top line and continued until the child failed to identify correctly three of a line's five symbols. Acuity was recorded as the smallest line on which the child correctly identified three symbols. On completion of testing of the right eye, the acuity of the left eye was measured.

MTI Photoscreening (MTIPS). Photoscreening was conducted using the MTI Photoscreener, a two-axis eccentric photorefractor that takes photographs at a distance of 1 m, using black-and-white Polaroid type 337 instant film (ASA 3200). Children were photographed in a dimly lit environment, and adequacy of fixation, focus, and pupil size was evaluated immediately by the tester. If the tester judged the photograph to be uninterpretable, another photograph was taken, with a recommended maximum of three photographs per child.

Scoring of photographs was performed after completion of each year's screening sessions by a panel of 11 raters, all of whom had completed a 1-day Prevent Blindness America (PBA) photoscreening course.[11,12] Scoring criteria used were those provided by PBA.[11,12] Each child's photograph(s) were scored as a composite (e.g., a top image that was interpretable in one photograph could be combined with a bottom image that was interpretable in another photograph to provide a score for the child) and recorded as Pass (normal), Refer (abnormal), or Retake (photographs uninterpretable). Inter- and intrarater reliability for this panel of "nonexpert" raters have been reported elsewhere.[11] Briefly, for individual pairs of raters, the pairwise κ-coefficients ranged from 0.12 to 0.74 for photographs scored as "pass," from 0.14 to 0.69 for photographs scored as "refer," and from −0.20 to 0.58 for photographs scored as "retake." Intra-rater reliability κ-coefficients for the eleven raters ranged from 0.53 to 0.80 for "pass" scores, from 0.22 to 0.83 for "refer" scores, and from 0.15 to 0.64 for photographs scored as "retake."[11]

The photographs were also scored by three highly experienced, expert raters at the Photograph Interpretation Center of the Department of Ophthalmology at Vanderbilt University, using a more detailed set of criteria.[11]

Keratometry Screening (KERS). Corneal astigmatism of the right then the left eye, was measured with the KM-500 auto keratometer, a portable hand-held, battery-operated device that operates at approximately 4 cm from the child's eye. The KM-500 uses a blinking red light as the fixation target and produces a printout of the keratometry values for each eye.

Autorefraction Screening (NCARS). NCARS of the right and then the left eye was performed with the Rmax K+, a portable hand-held, battery-operated device that operates at a distance of 2 to 5 cm from the child's eye, using an image of a tree against a blue sky as a fixation target. The instrument collects up to eight individual refractions per eye and provides a composite measurement of refractive error for each eye.

Cycloplegic Refraction. Cycloplegia was induced with a drop of 0.5% proparacaine followed by a drop of 2% cyclopentolate, followed five minutes later by a drop of 1% cyclopentolate. In small children (girls < 15 kg, boys < 16 kg) or those with a history of seizures, a drop of 1% cyclopentolate was substituted for the 2% cyclopentolate. At least 40 minutes after the first drop, refractive error was measured by autorefraction (Rmax K+) and by masked manual retinoscopy. A value for the best estimate of refraction (BER) was determined from the autorefraction and manual retinoscopy results, using an algorithm described elsewhere.[10,13]

Data Analysis

The goal of screening was to identify children requiring spectacles for refractive astigmatism. Disease-positive status was defined as BER cylinder ≥ 2.00 D for children < 48 months of age and ≥ 1.50 D for children ≥ 48 months of age, based on a survey of pediatric ophthalmologists.[14] Receiver operating characteristic (ROC) curves were used to compare screening results against the disease-positive or -negative status of the child. The ROCKIT software package was used to generate ROC curves based on a maximum-likelihood-ratio parameter estimation method.[15] This method allowed use of the *t* statistic to test for significant differences between ROC curves and to test if each ROC curve area differed from 0.5 (the null value).

RESULTS

Prevalence of Astigmatism

The prevalence of refractive astigmatism is shown in Table 2. Astigmatism ≥ 1.00 D was present in the right eye of 47.5% of subjects (maximum, 5.75 D) and in the left eye of 48.0% of subjects (maximum, 6.00 D). With-the-rule astigmatism (≥1.00 D plus cylinder, axis ≥ 60 to ≤120) was found in 98.9% (178/180) of astigmatic right eyes, and 100% (182/182) of astigmatic left eyes. Oblique astigmatism was present in two right eyes.

The proportion of children < 48 months of age prescribed spectacles for astigmatism ≥ 2.00 D in either eye[14] was 31.0% (54/174), while the proportion of older children (≥ 48 months) prescribed spectacles for astigmatism ≥ 1.50 D in either eye[14] was 35.1% (72/205), with an overall prevalence of significant astigmatism of 33.2% (126/379). No children had significant hyperopia (≥ 4.50 D sphere)[14] or significant myopia (≥ 2.50 D sphere if <48 months, ≥1.50 D sphere if ≥ 48 months)[14] in the absence of significant astigmatism.

TABLE 2. Distribution of Refractive Astigmatism, Determined by Cycloplegic Measurement of Refractive Error

	Refractive Astigmatism (D)						
Eye	0–<1.00	1.00–<2.00	2.00–<3.00	3.00–<4.00	4.00–<5.00	≥5.00	Total
Right	199 (52.5)	93 (24.5)	41 (10.8)	29 (7.7)	12 (3.2)	5 (1.3)	379
Left	197 (52.0)	90 (23.7)	45 (11.9)	28 (7.4)	12 (3.2)	7 (1.8)	379

Values in parentheses are percentages.

TABLE 3. Success Rates for Each of the Four Screening Methods

Screening Method	Screening Results Obtained*			
	36–47 Months	48–59 Months	60–63 Months	Total*
LSVAS	147/174 (84.5)	185/188 (98.4)	14/14 (100)	346/376 (92.0)†
MTIPS(A)‡	167/167 (100)	187/187 (100)	15/15 (100)	369/369 (100)§
MTIPS(B)‖	152/167 (91.0)	179/187 (95.7)	14/15 (93.3)	345/369 (93.5)
KERS	173/174 (99.4)	190/190 (100)	15/15 (100)	378/379 (99.7)
NCARS	172/174 (98.8)	190/190 (100)	15/15 (100)	377/379 (99.5)

* Values in parentheses are percentages.

† Excluded from the total are the 3 children who wore glasses during visual acuity screening.

‡ MTIPS(A): Success rates for obtaining an MTI photograph, irrespective of whether the photograph was later judged to be interpretable.

§ Excluded from the total are nine children who could not be tested because the camera was broken and one child for whom the photographs were misplaced.

‖ MTIPS(B): Success rates for obtaining an MTI photograph that was judged interpretable by at least 6 of the 11 nonexpert raters.

Success Rates

Success rates for screening with each of the four methods are shown in Table 3. Success rates for LSVAS, KERS, and NCARS are based on the number of subjects on whom we were able to obtain screening results from both eyes. Success rates for MTIPS were calculated as follows: MTIPS(A), the number of subjects in whom it was possible to take at least one photograph; and MTIPS(B), the number of subjects for whom photographs were judged to be interpretable by at least half of the 11 nonexpert raters. Among the 11 nonexpert raters, the proportion of children in whom the rater judged photograph(s) to be interpretable ranged from 58.3% (215/369) to 98.6% (364/369), with a median of 89.7%. For the three expert raters, the proportion of children in whom the rater judged photograph(s) to be interpretable were 91.3%, 93.8%, and 96.2%.

Success rates varied significantly by age for LSVAS ($\chi^2(2) = 25.1$, $P < 0.001$), with a lower success rate in 3-year-olds than in 4-year-olds ($\chi^2(1) = 21.2$, $P < 0.001$). Success rates did not vary with age in any of the other three screening methods. Overall success rates were significantly lower for LSVAS and MTIPS (Analysis B) than for KERS ($\chi^2(1) = 26.6$, $P < 0.001$, $\chi^2(1) = 20.6$, $P < 0.001$) or NCARS ($\chi^2(1) = 24.0$, $P < 0.001$, $\chi^2(1) = 18.2$, $P < 0.001$).

Screening Test Results

The distribution of results for LSVAS is presented in Table 4. Distance visual acuity in the worse-seeing eye ranged from 20/20 to 20/200 (median, 20/50).

Corneal astigmatism in the more astigmatic eye (KERS) ranged from 0.25 D to >6.00 D (median, 2.00 D). Refractive astigmatism in the more astigmatic eye (NCARS) ranged from 0.00 D to >6.00 D (median, 1.00 D).

TABLE 4. Distribution of Acuity Results for the 346 Children Who Did Not Wear Spectacles at the Time of Screening and Who Completed LSVAS of Both the Right and the Left Eye

Lea Symbols Acuity of the Worse-Seeing Eye (20/_)											
20	25	32	40	50	63	80	100	125	160	200	Total
1 (0.3)	18 (5.2)	55 (15.9)	63 (18.5)	54 (15.6)	52 (15.0)	51 (14.7)	22 (6.4)	14 (4.1)	9 (2.6)	7 (2.0)	346

Values in parentheses are percentages.

TABLE 5. Sensitivity and Specificity for Predicting the Presence of Significant Astigmatism on the Basis of Referring for Lea Symbols Distance Visual Acuity in the More Poorly Seeing Eye Being Equal to, or Worse than, the Acuity Shown

	Lea Symbols Acuity of the Worse-Seeing Eye (20/_)												
	16	20	25	32	40	50	63	80	100	125	160	200	Unable
Sensitivity*	1.00	1.00	1.00	1.00	0.98	0.92	0.73	0.48	0.22	0.09	0.04	0.02	—
Specificity*	0.00	0.00	0.00	0.08	0.31	0.56	0.70	0.79	0.89	0.92	0.95	0.98	—
Sensitivity†	1.00	1.00	1.00	1.00	0.98	0.93	0.75	0.50	0.26	0.14	0.09	0.06	0.05
Specificity†	0.00	0.00	0.00	0.07	0.28	0.51	0.63	0.72	0.80	0.83	0.86	0.88	0.90

* Based on data from the 346 children who completed Lea Symbols testing with each eye and who did not come to the test session wearing glasses.

† Based on data from all 376 children who were not wearing glasses when they came to the test session. Acuity results of the 30 children who did not complete Lea Symbols testing with each eye were scored as worse than 20/200.

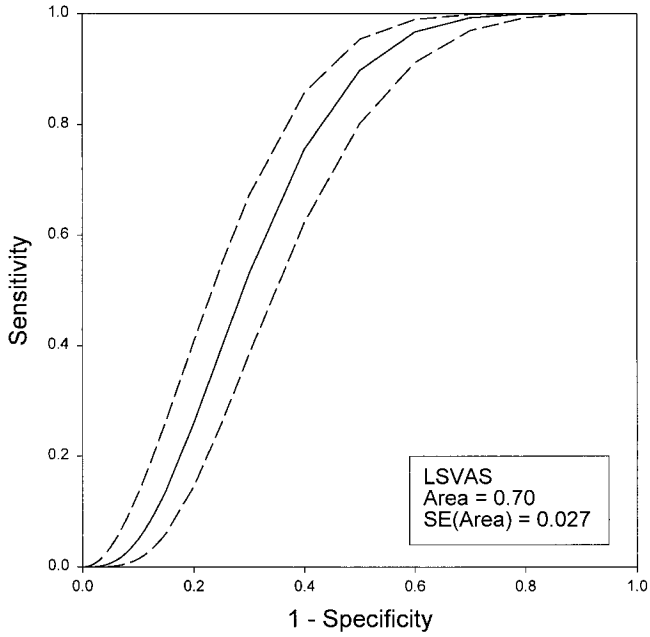

FIGURE 1. ROC curve, with 95% confidence interval, for Lea Symbols visual acuity screening (LSVAS).

Sensitivity and Specificity

LSVAS. Sensitivity and specificity results are shown in Table 5: (1) for the 346 children who completed acuity testing of each eye and were not wearing glasses at the test session, and (2) for all 376 children who were not wearing glasses at testing. For the second analysis, the results of the 30 children who were unable to complete acuity testing for both eyes were scored as Refer, as would be required in a "real world" screening setting where children who cannot complete screening are usually referred for follow-up examination. Figure 1 shows an ROC curve based on the data of all 376 children.[15] Requiring children to have an acuity of 20/40 or better in each eye to pass screening, as recommended in recent guidelines,[4,5] produces high sensitivity, but also low specificity (49% of the children [125/253] without significant astigmatism would be sent for a follow-up examination). Although 12 of these children had moderate, nonastigmatic refractive error that might warrant follow-up examination (6 had anisometropia ≥ 1.00 D spherical equivalent; 4 had hyperopia ≥ 3.00 D, and 2 had myopia ≥ 1.00 D; the remaining 119 had no ocular pathology or significant refractive error noted during the complete eye examination).

MTIPS. Sensitivity and specificity of the 11 nonexpert raters and the three expert raters in detecting significant astigmatism is shown in Table 6. Sensitivity and specificity data are presented in two ways: (1) for subjects whose data were scored as Pass or Refer by the observer, and (2) for all subjects, with Retakes scored as Refer. The first method permits comparison with previous reports of MTI Photoscreener sensitivity and specificity for detection of significant astigmatism,[16,17] whereas the second method provides estimates of sensitivity and specificity in a "real world" screening setting, where a child would be referred if unable to be screened. χ^2 analysis conducted on MTI data (analysis 2) indicated significant differences among nonexpert raters on sensitivity ($\chi^2(10) = 46.4$, $P < 0.001$) and specificity ($\chi^2(10) = 161.6$, $P < 0.001$), but no difference in sensitivity and specificity among expert raters.

To provide an ROC curve for MTIPS results, overall sensitivity and specificity based on the panel consensus score of the 11 nonexpert raters was calculated (Table 7 and Fig. 2), with Retakes scored as Refer. Highest sensitivity (97%) occurred when one or more of the raters voted to refer a child, but with this criterion, specificity was only 12%.

KERS and NCARS. Sensitivity and specificity for corneal astigmatism screening and for non-cycloplegic refractive astigmatism screening are shown in Table 8 and plotted as ROC curves in Figures 3 and 4, respectively. Referral of children with corneal astigmatism (KERS) of 2.25 D or more in either eye results

TABLE 6. Sensitivity and Specificity of the 11 Nonexpert Raters and the 3 Expert Raters in Detecting Significant Astigmatism in Either Eye on the Basis of MTI Photographs

	Nonexpert Raters											Expert Raters		
	A	B	C	D	E	F	G	H	I	J	K	1	2	3
Sensitivity*	0.41	0.82	0.64	0.48	0.59	0.71	0.55	0.59	0.63	0.60	0.60	0.54	0.54	0.53
Specificity*	0.86	0.41	0.72	0.87	0.79	0.78	0.87	0.91	0.85	0.88	0.90	0.91	0.94	0.94
n	251	215	330	334	315	345	353	336	364	292	298	355	346	337
Sensitivity†	0.66	0.89	0.67	0.53	0.65	0.72	0.58	0.66	0.64	0.70	0.69	0.57	0.58	0.58
Specificity†	0.63	0.24	0.64	0.78	0.67	0.72	0.85	0.86	0.84	0.71	0.74	0.88	0.89	0.87

* Based on data from children whose photographs were scored as Pass or Refer by the rater (Retakes omitted).
† Based on data from all children for whom photographs were taken ($n = 369$), with Retakes considered to be Refer.

TABLE 7. Sensitivity and Specificity for Predicting the Presence of Significant Astigmatism on the Basis of Number of Nonexpert or Expert Raters Voting to Refer Child on the Basis of MTI Photoscreener Images

	Number of Nonexpert Raters											Number of Expert Raters		
	1	2	3	4	5	6	7	8	9	10	11	1	2	3
Sensitivity	0.97	0.90	0.83	0.78	0.68	0.67	0.63	0.61	0.54	0.45	0.33	0.72	0.56	0.45
Specificity	0.12	0.40	0.53	0.66	0.71	0.79	0.83	0.87	0.89	0.93	0.96	0.82	0.88	0.95

$n = 369$; Retakes scored as Refer.

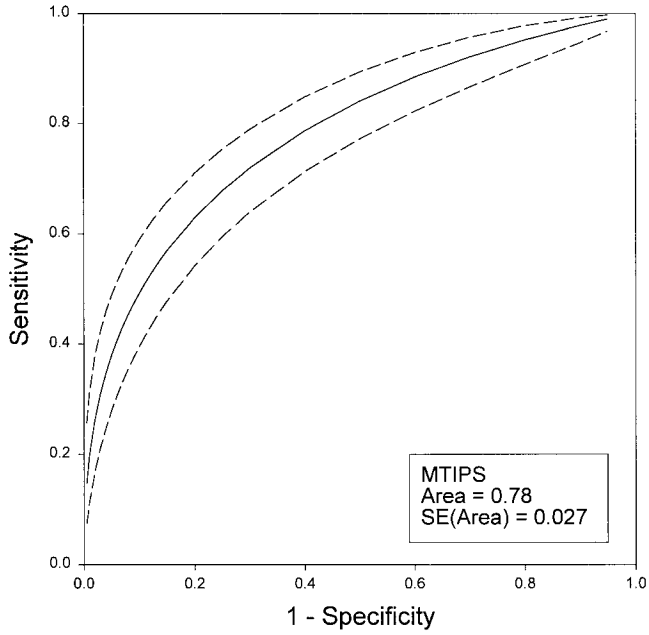

FIGURE 2. ROC curve, with 95% confidence interval, for MTI photoscreening (MTIPS).

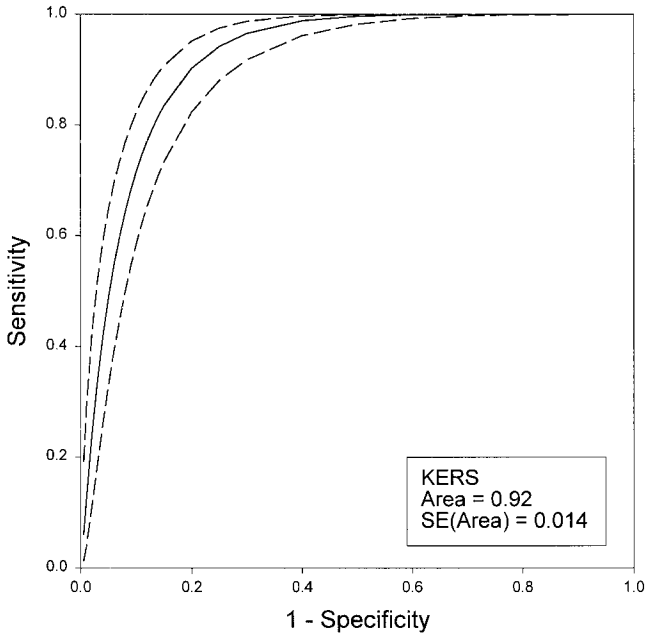

FIGURE 3. ROC curve, with 95% confidence interval, for keratometry screening (KERS) with the Marco Nidek KM-500 hand-held auto keratometer.

in sensitivity of 95% and specificity of 77%. Referral of children with noncycloplegic refractive astigmatism (NCARS) of 1.50 D or more in either eye results in sensitivity of 93% and specificity of 95%.

Comparison of ROC Curves. The area under the ROC curves (Figs. 1 to 4) provides a measure of the utility of each screening tool, ranging from a maximum of 1.00 (perfect) to 0.50 (no utility). As summarized in Table 9, the area under the curve for NCARS is significantly greater than that under the curves for the other three screening tools, the area under the curve for KERS is significantly greater than that under the curves for MTIPS and LSVAS, and the area under the curve for MTIPS is significantly greater than that under the LSVAS curve.

TABLE 8. Sensitivity and Specificity for Predicting the Presence of Significant Astigmatism on the Basis of KERS or NCARS

KERS			NCARS		
Corneal Astig (D)	**Sensitivity**	**Specificity**	**Refractive Astig (D)**	**Sensitivity**	**Specificity**
0.00	1.00	0.00	0.00	1.00	0.00
0.25	1.00	0.00	0.25	1.00	0.02
0.50	1.00	0.01	0.50	1.00	0.25
0.75	1.00	0.01	0.75	1.00	0.54
1.00	1.00	0.05	1.00	1.00	0.73
1.25	1.00	0.14	1.25	0.97	0.86
1.50	1.00	0.29	1.50	0.93	0.95
1.75	0.99	0.45	1.75	0.86	0.98
2.00	0.98	0.66	2.00	0.78	0.99
2.25	0.95	0.77	2.25	0.70	0.99
2.50	0.89	0.83	2.50	0.59	1.00
2.75	0.78	0.87	2.75	0.50	1.00
3.00	0.71	0.92	3.00	0.42	1.00
3.25	0.61	0.95	3.25	0.35	1.00
3.50	0.51	0.96	3.50	0.33	1.00
3.75	0.41	0.97	3.75	0.27	1.00
4.00	0.36	0.98	4.00	0.21	1.00
4.25	0.31	0.98	4.25	0.18	1.00
4.50	0.22	0.98	4.50	0.14	1.00
4.75	0.17	0.98	4.75	0.10	1.00
5.00	0.12	0.98	5.00	0.09	1.00
5.25	0.08	0.98	5.25	0.07	1.00
5.50	0.05	0.99	5.50	0.05	1.00
5.75	0.02	0.99	5.75	0.02	1.00
6.00	0.02	0.99	6.00	0.02	1.00
≥6.25 or unable	0.02	1.00	≥6.25 or unable	0.02	1.00

Referral is made when the astigmatism measured in the more astigmatic eye is equal to or greater than the amount shown on the line in the table.

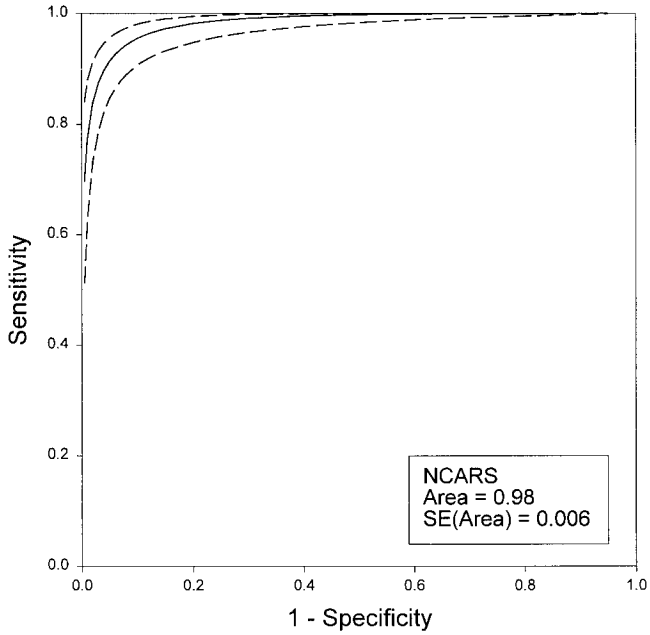

FIGURE 4. ROC curve, with 95% confidence interval, for noncycloplegic autorefraction screening (NCARS).

DISCUSSION

This study is the first to compare, in a sample of preschool-aged children, the effectiveness of different screening methods for the identification of young children who have high astigmatism. In addition to being tested with the most widely used method of vision screening (assessment of monocular visual acuity), each child was tested with three other methods: photoscreening, autokeratometry, and non-cycloplegic autorefraction.

Success Rates

The success rate for obtaining a screening result from each eye of a child varied across techniques. Measurement of monocular visual acuity for both eyes, using the Lea Symbols test, was possible in 92.0% of children but varied with age from 84.5% for 3-year-olds to 100% for 5-year-olds. A previous study reported an overall success rate for monocular visual acuity screening of 3- to 5-year-olds with the Lea Symbols test of 95%, with a lower success rate (92%) for 3-year-olds than for 4- (97%) or 5-year-olds (98%).[18] The slightly higher success rates in the previous study, compared with the present study, may be related to the previous study's use of a single screening line (20/40 for 3- and 4-year-olds; 20/32 for 5-year-olds), in contrast to the present study's requirement that children identify symbols on all lines of the chart, down to acuity threshold.

Although the success rate for obtaining a photoscreening photograph from a child was high, the proportion of photographs judged to be interpretable ranged from 58.3% to 98.6%, depending on which rater scored the photographs. These results are in agreement with those of two previous reports indicating wide variability across raters in the proportion of MTI photographs judged to be interpretable.[11,19]

The highest success rates were obtained for the two fully automated techniques: keratometry (99.7%) and noncycloplegic autorefraction (99.5%). Success rates were not reported in the only previous study in which preschool-aged children were tested with the Nidek KM-500 auto keratometer.[20] However, the nearly 100% success rate we found for the Rmax K+ is consistent with that reported previous studies in which a Retinomax was used with three- to five-year-old children.[21–23]

Sensitivity and Specificity

As shown in the ROC curves (Figs. 1 to 4) and in Table 9, there were substantial differences in the accuracy with which each of the four screening modalities identified children with significant astigmatism. Screening utility, as measured by the area under the ROC curve, was lowest for the visual acuity screening, significantly higher for photoscreening, significantly higher again for keratometry screening, and highest for noncycloplegic autorefraction.

LSVAS. As shown in Table 5, defining a screening Pass as acuity of 20/40 or better in each eye, as recommended in recent guidelines,[4,5] results in 92% sensitivity for detection of high astigmatism but specificity of only 56%. Relaxing the criterion for "passing" acuity screening to 20/50 or better reduced sensitivity to 73% and improved specificity to 70%. The low specificity indicates that there are many children in this age range who have no ocular abnormalities detectable on a complete eye examination but who fail to obtain an acuity score of 20/40 or 20/50 in each eye, perhaps because the task is too difficult for them or because they find it difficult to maintain attention long enough to reach their true acuity threshold. It is possible that providing young children with additional LSVAS training on the Lea test symbols and the testing procedure before the screening session or conducting re-screening on a different day for children who fail LSVAS would help to reduce the high proportion of children who perform poorly on visual acuity testing.

MTIPS. Median sensitivity across raters for correct identification of astigmatic children based on photographs scored as either Pass or Refer was 60% and median specificity was 86%. These results are similar to the sensitivities of 53% to 66% and 63%, and the specificities of 84% to 92% and 83%, reported in the two previous studies that have examined sensitivity and specificity of the MTI Photoscreener or its prototype for detection of astigmatism $>$ 1.50 D in young children, using photographs that could be scored as Pass or Refer.[16,17] Thus, even though the three studies used different criteria for defining significant astigmatism, there was general agreement that photoscreening failed to identify about one-third of astigmatic children but correctly identified most of the nonastigmatic children.

As might be expected in a busy screening session, there were some children in the present study who did not provide interpretable MTI photographs, even though the tester was permitted to rephotograph children if she judged the photograph to be uninterpretable during the testing session. When children whose photographs could not be scored (Retakes) were included in the Refer category, as would be necessary if no make-up screening session could be scheduled, median sensitivity increased slightly, to 66%, but median specificity decreased to 72%.

TABLE 9. Results of Statistical Comparisons between Screening Instruments for Differences in the Areas under the ROC Curves

	LSVAS	MTIPS*	KERS
LSVAS	—		
MTIPS*	0.007	—	
KERS	0.0001	0.0001	—
NCARS	0.0001	0.0001	0.0001

All values are significant after Bonferroni correction for multiple comparisons. Values are two-tailed *P* values.

* Nonexpert raters.

The across-rater variability in sensitivity and specificity found in the present study (Table 6) has also been reported in studies of non–Native American populations.[17,19,24] For example, one study reported that sensitivity for identification of astigmatism > 1.50 D ranged from 46% to 77% across six raters, whereas specificity varied from 79% to 89%.[24] Thus, the accuracy of the MTI Photoscreener as a screening instrument appears to be highly dependent on who scores the resulting photographs.

An alternative approach is to use rater-independent, computerized scoring of photoscreening images.[25] Initial results, however, suggest that this approach may be no more accurate than traditional scoring of photoscreening photographs for identifying high astigmatism in Native American preschool children.[26]

KERS. The combinations of sensitivity and specificity obtained with KERS (Table 8) are much higher than those obtained with either the LSVAS or MTIPS. Using a referral criterion of ≥2.25 D of corneal astigmatism, sensitivity and specificity for identification of high astigmatism were 95% and 77%, respectively, whereas a referral criterion of ≥2.50 D gave sensitivity of 89% and specificity of 83%. Previous research in this population of preschool children has shown that corneal astigmatism exceeds refractive astigmatism by an average of 0.85 D.[8] Therefore, it is not surprising that the referral criteria that give the highest sensitivity/specificity combination for KERS are values of ≥2.25 D and ≥2.50 D, which are 0.75 and 1.00 D, respectively, greater than the minimum amount of refractive astigmatism (≥1.50 D in children ≥48 months of age) defined as significant for children in the present study. Thus, the present results suggest that assessment of corneal astigmatism is a useful screening tool for identifying young children with high astigmatism.

NCARS. The most accurate screening tool that we evaluated was noncycloplegic autorefraction. With a referral criterion of ≥1.50 D of refractive astigmatism, sensitivity was 93% and specificity was 95%. The high sensitivity and specificity of NCARS likely result from (1) the similarity of measurements of astigmatism made with or without cycloplegia[22,23] and (2) use of the Rmax K+ for both screening and cycloplegic measurement of refractive error. Recent studies have shown, however, that there is excellent agreement between Retinomax measurements and both retinoscopy and subjective refraction measurements of cylindrical refractive error.[23,27–29]

Summary and Conclusions

In summary, the present study examined the effectiveness of four methods for screening a population of preschool-age children with a 33.2% prevalence of significant astigmatism. Results indicated that the most accurate screening method was noncycloplegic autorefraction. Nearly as effective was keratometry screening.

Considerably less effective was MTI Photoscreening. Photorefraction requires greater skill from both the photographer and the interpreter than does either autorefraction or autokeratometry. The photographer must decide in the field if the photograph demonstrates adequate pupil size and fixation, and then the photograph must be interpreted, either in the field or later, by one or more raters.

Visual acuity screening is also not as accurate as autorefraction or autokeratometry in this population. Use of a widely recommended screening criterion (20/40 or better to "pass") for this age group[4,5] results in high sensitivity but low specificity. Thus, visual acuity screening alone would result in overreferrals, with associated increased costs.[9]

In conclusion, the two instruments most effective in screening preschool-age children for astigmatism were the Retinomax K-Plus and the Nidek KM-500. Both are expensive when compared with the cost of an eye chart, but both are fast, require only one tester, and provide accurate identification of astigmatic children while minimizing the overreferrals of nonastigmatic children. The Nidek KM-500 has the advantages of being much smaller than the Retinomax K-Plus and of costing about one-third as much. However, it provides only information on corneal curvature, and therefore it might miss the rare media opacity that would be detected by the Retinomax K-Plus, which relies on the reflection of light from the fundus.

Finally, it should be noted that although the Nidek KM-500 and the Retinomax K-Plus without cycloplegia are excellent methods for screening for astigmatism in a preschool population, other screening techniques or protocols would be needed for ocular conditions such as strabismus, which require evaluation of ocular alignment, or for refractive errors such as high hyperopia, which could be missed in the absence of cycloplegia.

Acknowledgments

The authors thank the Tohono O'Odham Nation (Edward Manuel, Tribal Chairman), and parents, children, and Head Start staff who made this project possible. Assistance in collection of data was provided by Irene Adams, Morgan Ashley, Pat Broyles, Jenniffer Funk-Weyant, Christie Lopez, and Frances Lopez. The authors also thank Tom Leonard-Martin, PhD, MPH, Director of the Fundus Photograph Reading Center, Vanderbilt University Medical Center, for scoring MTI photographs, and the Data Monitoring and Oversight Committee of the National Eye Institute (Maureen Maguire, PhD, Chair, Cindy Norris, Donald Everett, MA, Jonathan Holmes, MD, and Karla Zadnik, OD, PhD).

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