Published in final edited form as:

Ophthalmology. 2011 March ; 118(3): 537–542. doi:10.1016/j.ophtha.2010.07.022.

Visual Acuity Testing Using Autorefraction or Pinhole Occluder as Compared with a Manual Protocol Refraction in Individuals with Diabetes

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Abstract

Purpose—To compare visual acuity (VA) scores obtained after autorefraction or using a pinhole occluder to scores obtained after refraction according to a standard clinical research protocol.

Design—Prospective, comparative case series

Participants—One hundred and ten study participants (209 eyes) with diabetes mellitus and a broad range of diabetic retinopathy severity and visual acuity (VA).

Methods—VA was measured after autorefraction by a Topcon KR-8000 autorefractor as well as after a Diabetic Retinopathy Clinical Research Network (DRCR.net) protocol manual refraction. The order of testing was randomized and examiners were masked to the source of each refraction. A second VA measurement, utilizing an identical DRCR.net manual refraction, was made in a subset of eyes (N = 144, 69%) in order to establish test-retest variability for comparison purposes. All eyes underwent VA testing using a pinhole occluder.

Main Outcome Measures—Best corrected VA as measured by the Electronic Early Treatment Diabetic Retinopathy Study Visual Acuity Test[®] (E-ETDRS).

Results—In all eyes, the median E-ETDRS VA letter score (EVA) obtained after manual refraction (MR-EVA) was 69 (Snellen equivalent 20/40), ranging from 4 to 93 (20/800 to 20/16). The median MR-EVA was slightly better than the median EVA obtained after autorefraction (AR-EVA), with a median difference (AR-EVA – MR-EVA) of –1 letter (25th, 75th percentiles: –4, 2 letters). The absolute difference between AR-EVA and MR-EVA was similar to the test-retest variability of MR-EVA alone. In contrast, MR-EVA was better than EVA obtained using a pinhole occluder (PH-EVA), (median PH-EVA – MR-EVA: –4 letters [–9, 0]), and had significantly less test-retest variability (P<0.001). Generally, the spherical equivalent of

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The authors have no financial conflicts of interest.

A complete list of all DRCR investigator financial disclosures can be found at www.drcr.net.

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autorefraction was slightly more hyperopic (or less myopic) than the spherical equivalent of manual refraction (median difference: +0.25 Diopters [0, +0.63 Diopters]).

Conclusions—Given the substantial time and effort required for training and certification of study protocol refractionists, and the similarity between AR-EVA and MR-EVA, further evaluation of autorefraction, but not pinhole occluder testing, as an alternative to the current clinical research gold standard of ETDRS protocol manual refraction in study participants with diabetic retinopathy is warranted.

Introduction

In both clinical practice and ophthalmic clinical trials, visual acuity (VA) measurement is a critically important endpoint that reflects visual function. The current gold standard measurement for best corrected VA in diabetic retinopathy clinical trials follows the standardized methodology of the Early Treatment Diabetic Retinopathy Study (ETDRS) protocol refraction and VA measurement. However, this approach entails a rigorous and often time consuming refraction prior to evaluation of VA.^{1, 2} The protocol also requires a certified refractionist which necessitates a significant investment in both cost and time. If alternative approaches to the detailed ETDRS protocol refraction yield equivalent outcomes, substantial benefit would be derived from the time and cost savings associated with greater ease of use and reduced dependence on certified refractionists. Furthermore, alternative automated approaches, which would increase standardization of the refraction procedure, could minimize potential bias by human refractionists.

Actual costs associated with refractionist certification vary widely and are not readily available for different practices across the country. Although government-sponsored study reimbursements may be lower than actual costs for many centers, a conservative estimate of potential cost savings associated with an alternative approach to manual refraction may be obtained using current Diabetic Retinopathy Clinical Research Network (DRCR.net) numbers. It is estimated that between certification and refraction procedures, total DRCR.net expense exceeds \$135,000 per year. This expense does not include opportunity costs of lost clinical site efficiency due to longer refraction examinations and the requirement for manual refraction-certified personnel. These burdens should be reduced substantially by the substitution of a faster refraction protocol requiring less operator training than the current gold-standard manual refraction.

There is currently widespread use of two alternative tests to estimate best corrected VA in daily ophthalmic clinical practice. However, these tests have not been formally evaluated for use in clinical trials for diabetic retinopathy. Autorefraction is the first of these alternatives and may have benefits of ease of use, increased objectivity, and fewer training requirements for examiners when compared with manual refraction. Previous studies suggest that, when compared with manual refraction, autorefraction generates comparable spherical equivalent refraction,³ comparable VA results,⁴ and has similar or better refraction test-retest reproducibility.^{5, 6} VA testing through a pinhole occluder is a second simple and rapid method used to compensate for refractive error. Pinhole occluders have been evaluated for VA screening prior to cataract surgery, for screening of patients at risk for VA loss, and in settings in which refraction is difficult or impossible.^{7, 8} Measurement of VA through a pinhole occluder also would represent significant time-savings over standard refraction followed by VA measurement if it were possible to eliminate the need for refraction itself.

In this study, we address whether a VA score obtained after autorefraction (AR-EVA) or through a pinhole occluder (PH-EVA) is a feasible alternative to the VA score obtained after gold-standard ETDRS protocol manual refraction (MR-EVA) for patients with diabetes. We have compared VA as measured by the Electronic Early Treatment Diabetic Retinopathy

Study Visual Acuity Test[®] (E-ETDRS) using autorefraction or through a pinhole occluder with that obtained using DRCR.net protocol manual refraction in a cohort of patients with a broad range of diabetic retinopathy severity and VA.

Methods

Individuals 18 years of age and older with diabetes mellitus were recruited from regularly scheduled clinics at the Beetham Eye Institute of the Joslin Diabetes Center, an eye care center specializing in diabetic eye disease. Prior to any study procedures, written informed consent was obtained from each study participant along with authorization for medical information disclosure in accordance with the Health Insurance Portability and Accountability Act. The study protocol was reviewed and approved by the Joslin institutional review board and the DRCR.net Executive Committee, and was in accordance with the Declaration of Helsinki.

All study procedures were performed at the time of a single study visit by experienced examiners certified by the DRCR.net for VA testing and refraction or VA testing alone, and data were recorded on standard forms. After obtaining demographic data (date of birth, ethnicity, gender, and education level) and medical history, both eyes of each study participant were evaluated according to the study protocol.

All VA measurements were performed on eyes prior to pupillary dilation according to the E-ETDRS method.⁹ This technique utilizes a computer-linked high-resolution monitor to present letters of standard luminance (85–105 candelas/meter²) and contrast (98%). Letters are presented one at a time accompanied by crowding lines. VA scores obtained using E-ETDRS have been validated in multiple studies and are acknowledged by the Food and Drug Administration as an acceptable primary clinical trial endpoint measure.^{9–11} The E-ETDRS yields a VA letter score (EVA) equivalent to an ETDRS VA score. As for a standard ETDRS VA score, a corresponding Snellen equivalent to the EVA can be estimated. For example, EVAs of 85 and 35 correspond to Snellen VA of 20/20 and 20/200, respectively.

All study participants had 3 VA tests on each eye 1) through a multihole pinhole occluder, 2) using autorefraction from a calibrated Topcon KR-8000 autorefractor, and 3) using DRCR.net protocol manual refraction performed by an experienced DRCR.net certified examiner (Figure 1). PH-EVA was obtained from each eye, over distance correction if worn. DRCR.net protocol refraction was then performed first on the right eye and second on the left eye (as detailed at www.drcr.net Accessed February 10, 2010). As per DRCR.net protocol, refractionists used a previous DRCR.net refraction as the basis for a starting refraction when available, and alternative methods (autorefraction, retinoscopy, neutralization of present correction, or plano) when not available. In 144 (69%) of the 209 eyes, immediately after the DRCR.net manual refraction, unmasked supplemental E-ETDRS testing was performed with the same DRCR.net manual refraction in place to generate a supplemental VA score (MR-EVAsupl) for purposes of assessing test-retest reliability of MR-EVA.

Autorefraction was then performed and a second examiner was provided the results of the manual refraction and autorefraction in random order. The examiner was masked to previously obtained EVAs and to which modality provided each refraction measurement. E-ETDRS testing was then performed using each of these refractions in trial frames to generate both a masked MR-EVA and a masked AR-EVA.

A slit-lamp anterior segment examination was performed to assess corneal clarity (clear, peripheral opacity/stain, central opacity/stain). Additional data were collected from

subsequent dilated funduscopy examinations and included lens status (clear lens, cataract, pseudophakia), level of diabetic retinopathy and diabetic macular edema, and primary cause of any visual loss.

Statistical Methods

Only eyes with a VA of 20/800 or better were included in the analyses. The refractive error transformation method, originally described by Long and later modified by Harris and Thibos,^{12–14} was used for the comparison between auto and manual refraction. Refractive error data were transformed into a spherical equivalent and 2 Jackson-Cross cylinder powers with axis at 180° and 45° using the Thibos method. The vector dioptric difference (VDD) was calculated from these transformations with a modified formula that scales the unit vector to match that of the Harris method.^{13–16} Distributions of differences in VA and refractive error according to refraction method are described using percentiles, rather than limits of agreement, as the differences were not normally distributed. Comparisons of differences among subgroups were made using regression models with generalized estimating equations (GEE) to account for correlation of data from 2 eyes of the same patient. Absolute differences between AR-EVAs and MR-EVAs were compared to absolute test-retest differences between MR-EVAs and MR-EVAsupl, using a paired t-test with GEE to account for correlation between eyes. A rank-based transformation for normality (van der Waerden scores) was applied to the differences prior to these analyses. Reported P values were not adjusted for multiple comparisons. However, due to the multiple comparisons, P values above 0.01 were not considered statistically significant. All statistical analyses were performed utilizing SAS software version 9.1 (Cary, North Carolina, USA).

Results

A total of 110 study participants (220 eyes) were enrolled in this study; 11 eyes from these study participants were not included in the analysis (7 eyes had VA <20/800 [EVA= 0] and 4 did not have VA testing performed), resulting in a total of 209 eyes evaluated. Mean age of study participants ($\pm$ standard deviation) was 64 ± 14 years and 57% were men. Median MR-EVA Snellen equivalent was 20/40 and MR-EVAs ranged from 20/16 to 20/800 (Table 1, available at <http://aaojournal.org>). Spherical equivalent of refractive error ranged from -8.00 diopters (D) to $+13.00$ D. The full range of diabetic retinopathy severity levels was represented in this cohort (Table 1, available at <http://aaojournal.org>).

Test-retest EVA Score Variability

MR-EVAsupl was obtained to serve as a benchmark for evaluation of VA variability when using autorefraction or a pinhole occluder. The median difference (MR-EVAsupl minus MR-EVA) was -1 letter (interquartile range -4 to $+2$ letters) and the median absolute difference was 3 letters (interquartile range 1 to 5 letters) (Figure 1; Table 2 [available at <http://aaojournal.org>]). Sixty-eight percent of test-retest scores differed by <5 letters, 97% by <10 letters, and 99% by <15 letters (Figure 2). Test-retest absolute differences in letter scores were not associated with level of MR-EVA ($P=0.76$).

Comparison of Visual Acuity Scores Using Manual Refraction Versus Autorefraction

The median MR-EVA was slightly better than the AR-EVA median. Of the 209 eyes evaluated, 192 (92%) were autorefracted successfully; of this group, 104 (54%) eyes had a MR-EVA 1 or more letters better than AR-EVA, 67 (35%) had an AR-EVA 1 or more letters better than MR-EVA and 21 (11%) had a MR-EVA and an AR-EVA that were exactly the same. The median difference (AR-EVA – MR-EVA) was -1 letter (interquartile range -4 to $+2$ letters) (Figure 3; Table 3). The median absolute difference was 3 letters, with 71% of scores differing by <5 letters, 92% differing by <10 letters, and 97% differing

by <15 letters (Figure 2). MR-EVA and AR-EVA differed by ≥ 5 letters in 56 eyes, with MR-EVA being better in 42 (75%) eyes and AR-EVA being better in 14 (25%) eyes. MR-EVA and AR-EVA differed by ≥ 10 letters in 15 eyes, with MR-EVA being better in 12 (80%) eyes and AR-EVA being better in 3 (20%) eyes.

The absolute differences did not vary with VA level ($P=0.19$), although there was a trend for the percentage of MR-EVAs versus AR-EVAs differing by <5 letters to be lower at worse levels of VA ($P=0.02$, Figure 2; Table 3). The differences and absolute differences between AR-EVAs and MR-EVAs were not associated with manual refraction spherical equivalent, gender, age, race, pupil size, corneal clarity, lens status, or order in which the masked E-ETDRS measurements were performed. However there was a trend towards an association of smaller absolute differences with more severe diabetic retinopathy ($P = 0.06$) (Table 4, available at <http://aaojournal.org>).

The absolute difference between AR-EVAs and MR-EVAs (Table 3) was not significantly different from the test-retest variability of MR-EVA (MR-EVA_{supl} - MR-EVA) ($P=0.42$). The similarities in absolute differences between AR-EVA and MR-EVA and the test-retest variability of MR-EVA were present for all VA subgroups (Figure 2).

Autorefractometry was unobtainable (i.e., resulted in a “no target” reading) in 17 eyes of 14 patients. The inability to obtain an autorefractometry was independently and significantly associated with worse VA ($P < 0.001$) and there was a trend towards association with more severe diabetic retinopathy ($P = 0.02$). Ninety-four percent ($N=16$) of eyes in which autorefractometry was not obtainable had a MR-EVA of 68 (Snellen equivalent 20/50) or worse. Eighty-nine percent of eyes that could not be autorefracted had proliferative diabetic retinopathy as compared with only 46% of eyes that were autorefracted successfully. Magnitude of refractive error (manual refraction spherical equivalent), gender, age, race/ethnicity, lens status, and corneal clarity were unrelated to the ability to autorefract successfully.

Comparison of Visual Acuity Scores Obtained Using Manual Refraction Versus Pinhole

The median difference between MR-EVAs and PH-EVAs (PH-EVA minus MR-EVA) was -4 letters and the median absolute difference was 5 letters (Table 5, available at <http://aaojournal.org>). Agreement between PH-EVAs and MR-EVAs was poor, with 48% of scores differing by <5 letters, 75% by <10 letters, and 89% by <15 letters, with the percentages being lower at worse VA levels ($P = 0.003$, Figure 2). The difference between PH-EVAs and MR-EVAs was significantly higher than the test-retest variability of MR-EVA alone ($P < 0.001$). Among the 108 eyes for which MR-EVA and PH-EVA differed by ≥ 5 letters, the MR-EVA was better in 93 (86%) eyes and the corresponding PH-EVA was better in 15 (14%), while among the 52 eyes in which the 2 scores differed by ≥ 10 letters, the MR-EVA was better in 48 (92%) eyes and the corresponding PH-EVA was better in 4 (8%) eyes.

Comparison of Refractive Error Determined with Autorefractometry and with Manual Refraction

Refractive errors measured by autorefractometry and manual refraction were similar (median VDD = 0.71 D, interquartile range 0.35 to 1.09 D), with the VDD differing by ≥ 1.00 D in 57 (30%) eyes, and by ≥ 2.00 D in only 17 (9%) eyes (Table 6). The autorefractometry spherical equivalent commonly resulted in a slightly more hyperopic (or less myopic) refraction than manual refraction spherical equivalent (median difference: +0.25 D, interquartile range 0 to 0.63 D, $P < 0.001$). A more hyperopic (or less myopic) autorefractometry was seen across all subcategories of VA, in both hyperopic and myopic eyes (Table 7, available at

<http://aaojournal.org>). In general, autorefraction was more hyperopic (or less myopic) whether the MR-EVA was better than the AR-EVA or vice versa. In the 12 eyes in which the MR-EVA was ≥ 10 letters better than the AR-EVA (Table 3), the VDD between the 2 refraction methods was < 1.00 D in 7 (58%) eyes. The autorefraction was more hyperopic (or less myopic) than the manual refraction in all 5 eyes in which the VDD was ≥ 1.00 D. In the 3 eyes with the AR-EVA ≥ 10 letters better than the MR-EVA (Table 3), the VDD was ≥ 1.00 D, with the autorefraction more hyperopic (or less myopic) than manual refraction, in 2 (67%) of the 3 eyes.

VA scores obtained were similar unless the autorefraction and the manual refraction were markedly different ($VDD \geq 2.0$ D). In the 17 eyes that met this criteria, 4 (24%) eyes had VA scores that differed by ≥ 10 letters and 2 (12%) eyes had VA scores that differed by ≥ 15 letters.

Discussion

In this cohort of patients with a wide range of diabetic retinopathy severity and VA, VA scores obtained after autorefraction were similar to those obtained after rigorous, DRCR.net protocol refraction. Among eyes with both AR-EVA and MR-EVA_{supl} (N=127) data, the correlations between AR-EVA and MR-EVA ($R=0.96$, 95% confidence interval (CI) 0.94–0.97) and MR-EVA_{supl} and MR-EVA ($R=0.95$, 95% CI 0.94–0.97) were both high. Although manual refraction provided slightly better overall VA scores than autorefraction, the absolute difference between AR-EVAs and MR-EVAs did not differ substantially from the test-retest variability of MR-EVA. These results suggest that autorefraction potentially could be utilized in the future instead of manual protocol refraction to determine best corrected VA in the majority of patients participating in diabetic retinopathy clinical research.

Eight percent of the entire cohort of eyes in this study could not be autorefracted. However, only 1 of 103 eyes (1%) with vision of $\geq 20/40$ could not be autorefracted. Thus, clinical trials utilizing cohorts with excellent vision (20/40 or better) would likely have high rates of successful autorefraction. In contrast, trials recruiting only eyes with poor vision or eyes with advanced diabetic retinopathy likely would be forced to resort more often to manual refraction after autorefraction yielded a “no target” reading. Some eyes autorefracted successfully at the beginning of a study may develop pathology that precludes subsequent autorefraction. Given the high degree of correlation between AR-EVA and MR-EVA ($R=0.96$) in this study, we believe it should be necessary to use manual refraction only in eyes when autorefraction is impossible or unreliable. Also, given the similarity of AR-EVA and MR-EVA in this study, the shift in refraction method would be expected to have no substantial impact on VA outcomes. Subsequent statistical analyses could adjust for method of refraction in order to eliminate confounding based on refraction method.

The substitution of autorefraction for manual refraction when possible would offer several potential benefits for clinical trial workload. Although some training and standardization would be required even with autorefraction, the use of autorefraction in a large proportion of eyes, in lieu of manual refraction, would substantially reduce dependence on skilled examiners to perform the time consuming task of refraction and reduce the need for certification of these examiners. Speed of the refraction procedure likely would increase. Significant savings in terms of time, cost, and labor might therefore accrue.

Although this study suggests that AR-EVA may be an acceptable substitute for MR-EVA, the high degree of variability and poor agreement of PH-EVA with MR-EVA makes using a pinhole occluder an unacceptable alternative to manual refraction for the accurate estimation

of best corrected VA. In 25% and 11% of eyes the PH-EVA was ≥ 2 and ≥ 3 lines (≥ 10 and ≥ 15 letters) different, respectively, from the corresponding MR-EVA.

Although this study did not demonstrate a substantial difference between autorefraction and manual refraction with regard to VDD, the routine substitution of autorefraction for a careful manual refraction is not recommended in daily ophthalmic practice. The goal of refraction in a clinic setting is to maximize patients' best corrected vision. The MR-EVA was generally better than the AR-EVA. Also, manual refraction offers the opportunity for patient interaction and immediate feedback that may maximize unmeasured components of functional vision and improve patient satisfaction with subsequent daily use correction.

Since this study utilized a single autorefractor model, we cannot exclude the possibility that other makes and models of autorefractors would give different results from those obtained here. Other limitations of this study include a relatively small cohort and the fact that it was performed at a single center and with highly experienced refractionists. The 4 optometrists and technicians responsible for manual refractions in this study have a cumulative experience of 74 years (range: 6–29 years). All of them have participated in numerous clinical trials and practice at an academic center that specializes in diabetic eye care and clinical trials for diabetic retinopathy. Their significant expertise would suggest that this study represents a best case scenario for minimizing MR-EVA test-retest variability and that in more generalized settings, the differences between the AR-EVA and the MR-EVA would be larger and potentially could favor the AR-EVA.

Given the substantial time, cost, and effort required to train and certify VA examiners for study protocol refraction, further evaluation of autorefraction as an alternative to manual refraction in clinical research is warranted. A larger, multicenter study is currently underway to determine the reproducibility of these results across a diverse range of clinical sites, autorefractors, and DRCR.net certified technicians with varying levels of experience.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Financial Support: Supported through a cooperative agreement from the National Eye Institute and the National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health, Department of Health and Human Services EY14231, EY14229, EY018817

The authors wish to acknowledge Ann Kopple, John Buabbud, and Julie Barenholtz for study coordination, preliminary statistical assistance and critical review of the data. In addition, we thank Drs. Paul Arrigg, Sharon Eagan, Tim Murtha, Deborah Schlossman, Sabera Shah, George Sharuk and Dorothy Tolls for referring patients and providing their expertise for ophthalmic examinations. This study could not have been completed without their assistance.

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Figure 1.

Difference Between Repeat Manual Refraction Electronic Early Treatment Diabetic Retinopathy Study (E-ETDRS) Visual Acuity Letter Score (MR-EVASupl) and Manual Refraction E-ETDRS Visual Acuity Letter Score (MR-EVA)

Solid reference line indicates median; dotted lines indicate 25th and 75th percentiles

Figure 2. Absolute Change from Manual Refraction Electronic Early Treatment Diabetic Retinopathy Study (E-ETDRS) Visual Acuity Letter Score (MR-EVA) with Repeat Manual Refraction E-ETDRS Visual Acuity Letter Score (MR-EVAsupl), Autorefraction E-ETDRS Visual Acuity Letter Score (AR-EVA) and Pinhole Occluder E-ETDRS Visual Acuity Letter Score (PH-EVA) Overall and According to Visual Acuity (VA) Level

Figure 3.
 Difference Between Autorefractive Electronic Early Treatment Diabetic Retinopathy Study (E-ETDRS) Visual Acuity Letter Score (AR-EVA) and Manual Refraction E-ETDRS Visual Acuity Letter Score (MR-EVA)
 Solid reference line indicates median; dotted lines indicate 25th and 75th percentiles

Table 3
Comparison of Visual Acuity Scores Following Autorefracton to Those Following Manual Refraction

	MR EVA Group [†]					
	Total	98-84 (≥20/20)	83-69 (20/25-0/40)	68-54 (20/50-20/80)	53-4 (20/100-20/800)	
N	192*	39	65	48	40	
Letter Difference^a - Median (25th, 75th percentiles)	-1 (-4, +2)	-1 (-4, 0)	-1 (-5, +1)	-1 (-3, +3)	1 (-4, +3)	
Letter Difference Group-n (%)						
≤-15	4 (2%)	0	1 (2%)	1 (2%)	2 (4%)	
-14 to -10	8 (4%)	3 (8%)	2 (3%)	1 (2%)	2 (4%)	
-9 to -5	30 (16%)	3 (8%)	16 (24%)	7 (14%)	4 (7%)	
-4 to +4	136 (65%)	33 (85%)	43 (65%)	34 (68%)	26 (48%)	
+5 to +9	11 (5%)	0	3 (5%)	5 (10%)	3 (6%)	
+10 to +14	2 (1%)	0	0	0	2 (4%)	
≥+15	1 (1%)	0	0	0	1 (2%)	
Absolute Value of the Letter Difference - Median (25th, 75th percentiles)	3 (1, 5)	2 (1, 4)	3 (1, 5)	3 (1, 5)	3 (2, 6)	
<5- n (%)	136 (71%)	33 (85%)	43 (66%)	34 (71%)	26 (65%)	
<10- n (%)	177 (92%)	36 (92%)	62 (95%)	46 (96%)	33 (83%)	
<15- n (%)	187 (97%)	39 (100%)	64 (98%)	47 (98%)	37 (93%)	

* - Excludes 17 eyes in which visual acuity scores using autorefracton (AR-EVA) were not obtainable (autorefracton resulted in a "no target" reading, 7 eyes with a manual refraction Electronic-Early Treatment Diabetic Retinopathy Study visual acuity score (MR-EVA) of 0 and 4 eyes in which visual acuity testing was not performed

^a AR-EVA minus MR-EVA

[†] - Visual acuity groupings based on masked MR-EVA scores

Table 6

Autorefractometer Versus Manual Refraction Vector Dioptric Difference

	N	Median (25 th , 75 th percentiles)	Vector Dioptric Difference [*]		
			≥0.25 D n (%)	≥0.50 D n (%)	≥1.00 D n (%)
Over All	192 ^a	0.71 (0.35, 1.09)	181 (94%)	138 (72%)	57 (30%)
MR-EVA Group					
≥20/20	39	0.56 (0.25, 0.75)	33 (85%)	25 (64%)	4 (10%)
20/25–20/40	65	0.56 (0.35, 0.90)	62 (95%)	42 (65%)	16 (25%)
20/50–20/80	48	0.75 (0.50, 1.03)	47 (98%)	38 (79%)	13 (27%)
20/100–20/800	40	1.46 (0.56, 2.08)	39 (98%)	33 (83%)	24 (60%)
Manual Refraction Spherical Equivalent Group					
<−3.00	25	0.90 (0.50, 1.77)	24 (96%)	21 (84%)	10 (40%)
−3.00<−1.00	28	0.90 (0.71, 1.82)	27 (96%)	24 (86%)	13 (46%)
−1.00<−1.00	96	0.56 (0.35, 0.90)	89 (93%)	62 (65%)	21 (22%)
+1.00<+3.00	35	0.75 (0.35, 1.03)	33 (94%)	26 (74%)	9 (26%)
≥+3.00	8	0.81 (0.25, 2.46)	8 (100%)	5 (63%)	4 (50%)

* Calculated by obtaining the Jackson-cross cylinder power (axis 180 degrees), and the Jackson-cross cylinder power (axis 45 degrees) from cylinder and axis and then computing the Vector Dioptric Difference (VDD) of the spherical equivalent and two Jackson cross cylinders for the auto and manual refractions using Thibos Method.^{14–16}

^aExcludes 17 eyes in which an autorefractometer cylinder was not obtainable (autorefractometer resulted in a “no target” reading), 7 eyes with a manual refraction Electronic-Early Treatment Diabetic Retinopathy Study (E-ETDRS) visual acuity score (MR-EVA) of 0 and 4 eyes in which visual acuity testing was not performed