Original Research Article

Comparison of Autorefractometry and Aberrometry with subjective refraction in myopic refractive errors

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Abstract

Background: For the assessment of refractive errors, various methods are available. Usually an objective method like retinoscopy or autorefractometry is carried out first, which is further refined by subjective acceptance' before prescribing the spectacles. Though retinoscopy is considered the gold standard, autorefractometry is commonly used as a good starting point of objective refraction as it is easier and less time-consuming. Aberrometry refers to analysis of optical aberrations, both lower order aberrations and higher order aberrations, widely used in refractive surgical practice, and is considered an accurate objective method of assessing the eye's refractive status. **Purpose:** The objective of this study was to compare the refractive assessment by autorefractometer, aberrometer and subjective refraction in myopic and myopic astigmatic refractive errors and to find any possible correlation between higher order aberrations and degree of refractive error in Indian eyes. **Materials and Methods:** 300 eyes of one hundred and fifty healthy individuals aged between 10 and 38 years were recruited during examination. Refractive corrections were converted to sphero-cylindrical correction for the ease of calculation. Data were statistically evaluated using ANOVA. **Results:** Mean value of refractive assessment among subjective refraction was -2.79 ± 2.18D (Diopters), in autorefractometer it was -3.44 ± 2.49D and in aberrometry it was -3.49±2.32D. There was statistically no significant difference between autorefractometry and aberrometry (p = 0.766). Comparing the refractive corrections, both autorefractometry and aberrometry results were significantly different from subjective refraction (p< 0.001).Also, there was statistically significant negative correlation between Z (4,0) and AR, (Pearson coefficient -0.172), Z(4,0) and SR (Pearson coefficient -0.131), and Z(4,0) and ABR (Pearson coefficient - 0.189). **Conclusion:** In our study, there was no significant difference between the aberrometer and autorefractor derived measures of refractive errors. The Hartmann – Shack aberrometerwas found to have a range of accuracy similar to that of autorefraction. However, there existed statistically significant differences between autorefractometer and aberrometer values with subjective refraction. Hence, while prescribing spectacles, the data obtained from either of these instruments would alone not be sufficient and can only be used as a starting point for subjective refraction. Also, higher order aberrations decreased with increase in myopia.

Key Words: Autorefractometry, Aberrometry.

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INTRODUCTION

Spectacle prescription is both a delicate art and science. It balances an objective parameter about the refractive status of the eye like retinoscopy or autorefractometry with subjective refraction[1]. Traditionally, a subjective test is performed following an objective test to determine sphero cylindrical refraction with which subject reaches best visual acuity. However, variability in measurements when compared with the subjective manifest refraction limits the autorefractors direct prescribing capability[2-6]. Commonly it is used as a good starting point for subjective refraction for most patients. Aberrometry refers to measurement of optical aberrations, both lower

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order aberrations and higher order aberrations. The basis of aberrometry is based on the Hartmann–Shack principle[15-16]. In contrast to auto refractors, which can measure only lower order aberrations (sphere, cylinder and axis) wave front aberrometers measure both lower order and higher order aberrations (spherical aberration, coma, trefoil etc). Aberrometers enable the detection and correction of ocular aberrations by applying the root mean square (RMS) of Zernike coefficient polynomials[19-20]. Several studies have used these newer technologies to examine the relationship between monochromatic aberrations and myopia[21-23]. The aim of our study was to compare the values derived from autorefractometer, aberrometer and subjective refraction in myopic and myopic astigmatic refractive errors in Indian eyes and to find any possible correlation between higher order aberrations and degree of refractive error.

MATERIALS AND METHODS

This cross-sectional study was conducted in Department Of Ophthalmology, Amrita Institute of Medical Sciences, Kochi on an outpatient basis from January 2016 to August 2016.300 eyes of 150 subjects were taken for the study after procuring consent and hospital ethical committee clearance. The inclusion criteria were[1] normal people between 18 and 35 years of age with myopia and myopic astigmatism and[2] with best corrected visual acuity (BCVA) greater than or equal to 20/20. We excluded[1] all patients with BCVA less than 20/25[2] with any systemic diseases[3] with any ocular pathology[4] who had undergone cataract extraction or refractive surgery. All subjects underwent [a] auto-refractometry [b] aberrometry followed by [c] subjective acceptance using standard Snellen's visual acuity chart. This was followed by a comprehensive ocular examination, including non-contact tonometry, slit lamp examination and retinal examination by an ophthalmologist.

a. **AUTOREFRACTOMETRY:** Was done using Auto keratorefractometer (KR-8100, Topcon, Japan),which works according to the Scheiner double pinhole principle. The measurements are taken with the aid of a joystick once the subject's pupil was aligned and focused on the built-in viewing monitor of the instrument.
b. **ABERROMETRY:** Was done with WASCA Analyser, Carl-Zeiss which measures the eye's wave front aberration function based on the Shack-Hartmann principle. Under scotopic conditions one reading from each eye was obtained and recorded for analysis. The RMS OPD, RMS OPD_{HO} were also determined in addition to sphere, cylinder and axis. The light source used for measurement is an 840-nm infrared super luminescent diode, and results are converted to a user-selected wavelength (default setting 550 nm). After each measurement, the attached computer displays a color map of both the total and higher-order wave front aberration, along with a numerical list showing the spherocylindrical refractive error to the nearest 0.01 D (corneal or spectacle plane; plus- or minus-cylinder format), pupil size to the nearest 0.1mm, total and higher-order root mean square wave front error, peak-to valley wave front errors, and Zernike coefficients.
c. SUBJECTIVE REFRACTION of both the eyes was measured under normal illumination with a standard Snellen projected chart at 20 feet (6 m). From the degree of ammetropia, retinoscopy and glass prescription the degree of refractive error is corrected. Maximum visual acuity is tested using pinhole vision. The endpoint was the lens power that resulted in the best VA and/or visual comfort. Duochrometest was also checked before finalisation of the power. For calculation purposes, Snellen acuities were converted to log minimum angle of resolution (log MAR) and refractive correction is corrected to spherical equivalent by adding sphere to half power of cylinder (SE = S +C/2).

Statistical Methods: Data tabulated using MS excel and analyzed using software IBM SPSS version 20.Quantitatives variables expressed as mean and standard deviation. Data was analysed using ANOVA.

RESULTS

Age and sex- Of the 150 subjects there were 99 females (66%) and 51 males (34%). The mean age was 22.23 ± 5.3yrs.

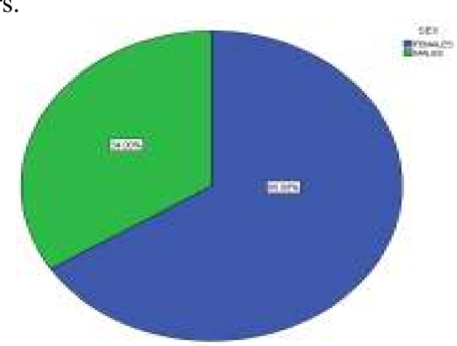

Figure 1:

Type of refractive error– Out of 300 eyes, 128 eyes (42%) have simple myopia, 41eyes (14%) have simple myopic astigmatism and 131(44%) have compound myopic astigmatism.

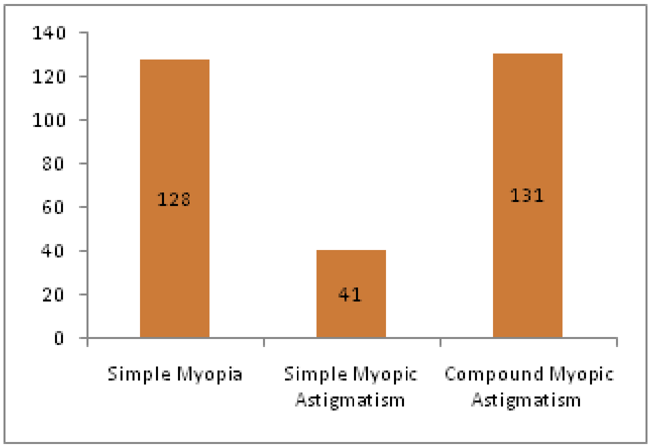

Figure 2:

Table 1: Comparison of subjective refraction (SR) with autorefractor (AR) and aberrometer (ABR)

Methods Compared		Greater	Equal	Less
SR	AR	243	25	32
	ABR	269	3	28
AR	ABR	158	0	142

When subjective refraction is compared with autorefractometer, 243eyes (81%) have value greater than subjective refraction, 25 eyes (8.3%) have value equal to subjective refraction and 32 eyes (10.7%) have value less than subjective refraction. When subjective refraction is compared with aberrometry, 269 eyes (89.6%) have value greater than subjective refraction, 3 eyes (1%) have value equal to subjective refraction and 28 eyes (9.3%) have value less than subjective refraction. When autorefractometer reading is compared with aberrometry, 158 eyes (52.6%) have aberrometry reading higher than autorefractometry reading whereas 142 eyes (47.3%) have aberrometry reading less than autorefractometry reading (Table.1).

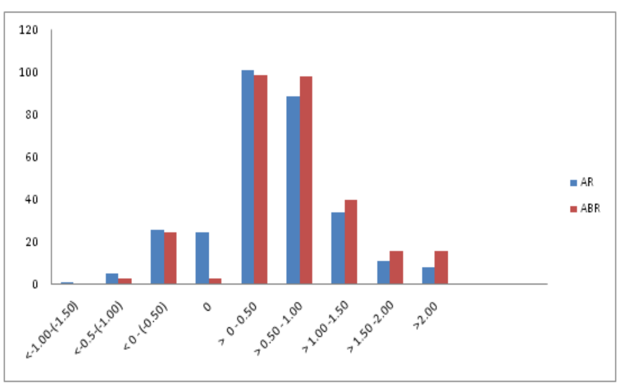

Figure 3: Comparison of subjective refraction (SR) with autorefractor (AR) and aberrometer (ABR)

When subjective refraction (SR) is compared with autorefractometer (AR), 26 eyes come under the range 0-0.50D, 5 eyes come under the range 0.5- 1.00D, and 1 eye comes under the range 1.00- 1.50D, with autorefractometer value less than subjective refraction whereas 101 eyes come under the range 0-0.50D, 89 eyes come under the range 0.50-1.00D, 34 eyes come under the range 1.00-1.50D,11 eyes come under the range 1.50-2.00D and 8 eyes have refractive error greater than 2.00D, with autorefractometer value greater than subjective refraction. When subjective refraction (SR) is compared with aberrometer (ABR) 25eyes come under the range of 0- 0.50D and 3 eyes comes under the range 0.5-1.00D with aberrometer value less than subjective refraction whereas 99 eyescome under the range 0-0.50D, 98 eyes come under the range 0.50-1.00D, 37eyes come under the range 1.00-1.50D, 16 eyes come under the range 1.50-2.00D and 16 eyes have refractive error greater than 2.00D, with aberrometer value greater than subjective refraction (Diagram 3)

Statistical Analysis: Data were expressed as mean ± standard deviation. A paired t test was used to compare the spherical equivalent between AR and SR, and ABR and SR. Repeated measure analysis was used for comparison of 3 methods. Pearson correlation method was used to find the relation between RMS_{HO} and Z(4,0) and also with autorefractometer subjective refraction and abberometry. A p value ≤ 0.05 was considered to be statistically significant. The software IBM SPSS version 20 was used for statistical analysis.

Table 2: Spherical equivalents of subjective refraction and measured Autorefractometry, Aberrometry Paired t test

	SR mean ± sd	AR mean ± sd	ABR mean ± sd
SE	-2.79 ± 2.18	-3.44 ± 2.49	-3.49 ± 2.32
p value compared with subjective refraction	-	< 0.001*	< 0.001*

*Statistically significant, SE- Spherical equivalent

Table 3: Repeated measure analysis

Methods	Mean	SD	p value
SR	-2.79	2.18	
AR	-3.44	2.49	< 0.001
ABR	-3.49	2.32	

There is a significant difference in the refractive values (F=132.060, p= < 0.001) in the three refractive measurements (F= 132.060, p=<0.001). Value of refractive assessment among SR was -2.79 ± 2.18. In AR it was -3.44 ± 2.49 and in ABR it was -3.49± 2.32.

Table 4: Comparison of SR, AR, and ABR

Methods Compared		Mean Difference	SE	p value
SR	AR	-6.46	0.052	<0.001
	ABR	-7.04	0.041	<0.001
AR	ABR	-0.058	0.051	0.0766

Bonferoni test is applied for pair wise comparison. The refractive corrections were different significantly from SR with AR and SR with ABR (P < 0.001). There is statistically no significant difference between AR and ABR (p = 0.766) (Table.4). Correlation of spherical aberration Z(4,0) with AR, SR and ABR There was statistically significant negative correlation between spherical aberration measured by aberrometer as Z (4,0) and AR (Pearson coefficient - 0.172), Z(4,0) and SR (Pearson coefficient -0.131) and Z(4,0) and ABR (Pearson coefficient -0.189).

Table 5: Correlation of Z (4, 0) with AR, SR and ABR

Methods	Z(4,0)	
	Pearson correlation coefficient	p value
AR	-0.172	0.003
SR	-0.131	0.023
ABR	-0.189	0.001

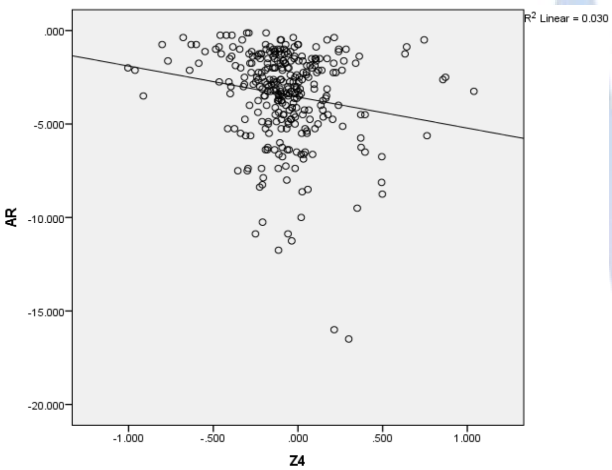

Figure 4: Correlation between Z (4,0) and Autorefractometry reading

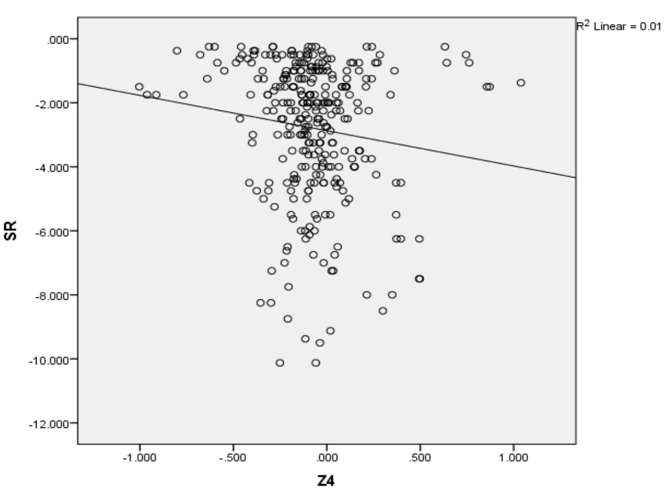

Figure 5: Correlation between Z(4,0) and subjective refraction

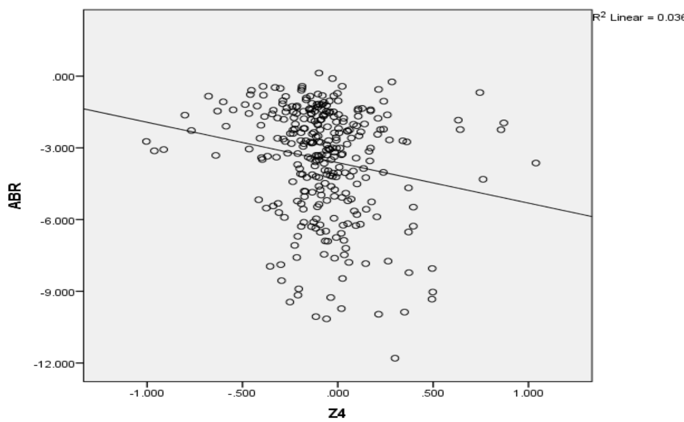

Figure 6: Correlation between Z (4,0) and Aberrometry

Frequency of higher order aberrations–Root mean square value is a sum total of all higher order aberrations and a value of more than 0.3 is considered high. Out of 300 eyes, 55 eyes (18.3%) had high RMS_{HO} and 245 eyes (81.7%) had low RMS_{HO} values.

Table 6:

	Frequency	Percentage
High RMS_{HO}	55	18.3
Low RMS_{HO}	245	81.7

DISCUSSION

Nowadays there are many techniques for establishing the best optical correction of refractive errors. Subjective refraction has been traditionally accepted as the gold standard for refraction and prescribing spectacles[1]. Usually a subjectivetest is performed following an objective test that includes autorefractometry or retinoscopy to determine spherocylindrical refraction with which subjects reaches best visual acuity. However, variability in measurements when compared with the subjective manifest refraction limits the autorefractors direct prescribing capability[(2-6)]. Commonly it is used as a good starting point for subjective refraction for most patients. Aberrometry refers to analysis of optical aberrations. They also measure lower order aberrations in addition to higher order aberrations. Objective autorefractors and more recently wave front aberrometers have gained clinical popularity because of their reasonable refractive accuracy, repeatability, ease of use, and time-saving capability[7-11]. There are multiple distinct measuring principles for autorefractors[12] and wave front aberrometers[13-14] resulting in unique technology for different marketable units. The basis of aberrometry is based on the Hartmann–Shack principle[15-16]. Monochromatic aberrations include lower-order and higher-order aberrations. Autorefractors are limited to measuring lower order aberration (sphere, cylinder and axis) whereas wave frontaberrometers measure both lower order and higher order aberrations (spherical aberration, coma, trefoil etc) and provide clinicians the ability of routinely measure aberrations of their patient. It has been suggested that higher order aberrations are the reasons why many patients complain of halo, glare, and decreased contrast sensitivity even after successful keratorefractivesurgeries[17,18]. Aberrometers enable the detection and correction of ocular aberrations by applying the root mean square (RMS) of Zernike coefficient polynomials[19-20]. Several studies have used these newer technologies to examine the relationship between monochromatic aberrations and myopia[21-23]. The aim of our study was to compare the values derived from autorefractometer, aberrometer and subjective refraction in myopic and myopic astigmatic refractive errors in Indian eyes and to find any possible correlation between higher order aberrations and degree of refractive error. Out of 300 eyes of 150 patients with mean age of 22.23 ± 5.3years, it was found that both the aberrometer and autorefractor provided reliable information on the lower order aberrations. There was no statistically significant difference between autorefractor (AR) and aberrometer (ABR) values. However there existed statistically significant difference between autorefractor derived values andaberrometry derived values with subjective refraction values. The mean difference between subjective refraction and autorefractor was 0.65D and that of subjective refraction and aberrometry is 0.7D. It was seen that the aberrometer showed slightly greater difference from subjective refraction when compared to the autorefractor, but the difference was not statistically relevant. 82 % of autorefractor reading is within ± 1.00D of subjective refraction, while 76%of the aberrometer readings were within ±1.00D of subjective refraction. 81% of the autorefractometry reading and 89.6% of the aberrometry reading over correct myopia compared to subjective refraction. Also, there was a negative correlation between spherical aberration Z (4,0) and higher powers in all the three values - autorefractor (Pearson coefficient - 0.172), subjective refraction (Pearson coefficient -0.131) and aberrometry (Pearson coefficient -0.189), which meant spherical aberration diminished with higher degree of myopia. In myopes, low RMS_{HO} (81.7%) is more compared to high RMS_{HO} (18.3%). Out of 55 high RMS_{HO}65.5% and 50% come in low degree myopia in subjective refraction and aberrometry respectively. Our findings were consistent with that of study done by Cooper J, *et al* comparing Z-view aberrometer, Humphrey autorefractor and subjective refraction. The differences in spherical equivalents measured by the aberrometer and autorefractor with respect to subjective refraction of 0.118 (±0.311) and-0.193 (±0.474) diopters, respectively. Both instruments tend to overcorrect astigmatism of less than -1.25 and -0.75 D, respectively, and insome cases by as much as -0.87 D[2]. Bennett *et al*, in a similar study of 120 eyes concluded that the autorefractor (Nidek 530 AR) showed a better agreement with subjective refraction when compared to the aberrometer, (Nidek OPD-II Scan wave frontaberrometer), but the difference was not statistically significant. Agreement between autorefractor and subjective refraction was slightly stronger than between aberrometry and subjective refraction. It was found that around 80% of autorefractor derived and 72% of aberrometerderived results were within ±0.25D of subjective refraction measurements[40]. Lebow K A *et al* studied 174 eyes of 100 subjects with a mean age of 51.7years. They found that both the Canon RK-F2 (autorefractor) and Carl Zeiss Vision i. Profiler Plus (wave frontaberrometer) had differences between the spherical equivalent and the subjective refraction findings when clinically significant difference of > 0.25 D was taken as significant. Aberrometry values in general were slightly more minus than autorefractor values. However, in contrast to our study RKF2autorefractorvalues were similar to subjective refraction (-0.11 D)[39]. Salmon *et al*, compared the refraction(spherical error and astigmatism) obtained from aberrometer (COAS Shack-Hartmann)with that from an autorefractor (Nidek ARK-2000) and conventional subjective refraction on 20 patients concluded similar performances among all the three different measurements while our study conclude similar performance between autorefractor and aberrometry only. In contrast, they also pointed that without cycloplegia, both the COAS and autorefractor had mean power vector errors of 0.3 to 0.4D and cycloplegia improvedautorefractor accuracy by 0.1 D, while COAS accuracy remained the same. Like their study, we also concluded that COAS accuracy, repeatability, and instrumentmyopia were similar to those of the autorefractor[10]. Hong-ZinLin *et al*, compared wave frontrefraction, and autorefraction, using Topcon autorefractor and Allegret to wave analyzer respectively with subjective refraction using cycloplegia, and pointed that both cycloplegicwavefront refraction and autorefraction showed good correlations with subjective refraction. They concluded that autorefraction gives a better estimate of subjective manifest refraction than wavefrontrefraction in both the spherical equivalent and astigmatism, with usage of cycloplegia[38]. To conclude, we found that both aberrometry and autorefraction arequite accurate, objective tools, to assess the refractive status of the eye, but aberrometry does not add more accuracy to autorefractometer value. Hence, while prescribing spectacles, subjective acceptance cannot be obviated.

REFERENCES

1. Goss DA, Grosvenor T. Reliability of refraction - a literature review. J Am OptomAssoc1996; 67:619-30.
2. Cooper J, Citek K, Feldman JM. Comparison of refractive error measurements in adults with Z-View aberrometer, Humphrey autorefractor, and subjective refraction. Optometry 2011; 82:231-40.
3. Elliott M, Simpson T, Richter D, Fonn D. Repeatability and accuracy of automated refraction: a comparison of the Nikon NRK8000, the Nidek AR-1000, and subjective refraction. Optom Vis Sci 1997; 74:434-8.
4. Kinge B, Midelfart A, Jacobsen G. Clinical evaluation of the Allergan Humphrey 500 autorefractor and the Nidek AR-1000 autorefractor. Br J Ophthalmol 1996; 80:35-9.
5. Gwiazda J, Weber C. Comparison of spherical equivalent refraction and astigmatism measured with three different models of autorefractors. Optom Vis Sci 2004; 81:56-61.
6. Nissman SA, Tractenberg RE, Saba CM, Douglas JC, Lustbader JM. Accuracy, repeatability, and clinical application of spherocylindrical automated refraction using time-based wavefrontaberrometry measurements. Ophthalmology 2006; 113:577.
7. Cleary G, Spalton DJ, Patel PM, Lin PF, Marshall J. Diagnostic accuracy and variability of autorefraction by the Tracey Visual Function Analyzer and the Shin-Nippon N Vision-K 5001inrelation to subjective refraction. Ophthalmic Physiol Opt 2009; 29:173-81.
8. Allen PM, Radhakrishnan H, O'Leary DJ. Repeatability and validity of the Power Refractor and the Nidek AR600-A in an adult population with healthy eyes. OptomVisSci 2003; 80:245-51.
9. Salmon TO, van de Pol C. Evaluation of a clinical aberrometer for lower-order accuracy and repeatability, higher-order repeatability, and instrument myopia. Optometry 2005; 76:461-72.
10. Salmon TO, West RW, Gasser W, Kenmore T. Measurement of refractive errors in young myopes using the COAS Shack-Hartmann aberrometer. Optom Vis Sci 2003; 80:6-14.
11. YeungIY, MantryS, CunliffeIA, BensonMT, ShahS. Correlation of Nidek OPD-Scan objective refraction with subjective refraction. J Refract Surg 2004; 20:S734-6.
12. DaveT. Automated refraction: design and applications. Optom Today2014; June4:28-32.
13. Campbell CE. Determining spherocylindrical correction using four different wavefront error analysis methods: comparison to manifest refraction. J Refract Surg 2010; 26:881-90.
14. Cervin ˜o A, Hosking SL, Monte ´s-Mico ´ R, Bates K. Clinical ocular wavefront analyzers. J Refract Surg 2007;23:60
15. J. Liang, B. Grimm, S. Goelz, and J. Bille, ''Objective measurement of the wave aberrations of the human eye with the use of a Hartmann–Shack wave-front sensor,'' J. Opt. Soc. Am. A 11, 1949–1957 (1994).
16. B. Platt and R. V. Shack, ''Lenticular Hartmann screen,'' Opt. Sci. Center Newsl. (University of Arizona) 5, 15–16 (1971).3-16.
17. Chalita M R, Chavala S, et al. Wave frontanalysys in post-LASIK eyes and its correlation with visual symptoms, refraction, and topography. Ophthalmology; March 2004, Vol 111(3) P: 447-453.
18. Seiler T, Kaemmerer M, et al. Ocular optic aberrations after photorefractive keratectomy for myopia and myopic astigmatism. Arch Ophthalmol. 2000; 118(1) ; 17
19. Llorente L, Barbero S, Merayo J, Marcos S. Total and corneal optical aberrations induced by laser in situ ketatomileusis for hyperopia. J Refract Surg 2004; 20:203-216.
20. Barbero S, Marcos S, Merayo-Lloves J, MorenoBarriuso E. Validation of the estimation of corneal aberrations from videokeratography in keratoconus. J Refract Surg 2002; 18:263-270.
21. Marcos S, Moreno-Barriuso E, Llorente L, Navarro R, Barbero S. Do Myopic Eyes suffer from Larger Amount of Aberrations? Myopia 2000: Proceedings of the VIII International Conference on Myopia 2000; 118 - 21.
22. He JC, Sun P, Held R, Thorn F, Sun X, Gwiazda JE. Wavefront aberrations in eyes of emmetropic and moderately myopic school children and young adults. Vision Res 2002; 42:1063-70.
23. Paquin MP, Hamam H, Simonet P. Objective measurement of optical aberrations in myopic eyes. Optom Vis Sci 2002; 79:285-91.
24. Joubert L, Harris WF. Excess of autorefraction over subjective refraction: dependence on age. Optom Vis Sci 1997; 74:439-44.
25. Bullimore MA, Fusaro RE, Adams CW. The repeatability of automated and clinician refraction. Optom Vis Sci 1998;75:617-22
26. Dunaway D, Berger I, "World wide Distribution of Visual Refractive Errors and What to Expect at a Particular Location". Infocusonline.org.
27. Fredrick DR "Myopia". (May 2002). BMJ 324 (7347): 1195–9. doi:10.1136/bmj.324.7347.1195. PMC 1123161. PMID12016188.
28. David Abrams. Duke-Elder's practice of refraction. 1983; 10:54-60
29. American Academy of Pediatrics, Committee on Practice and Ambulatory Medicine and Section on Ophthalmology. 2002. Use of photo-screening for children's vision screening. Policy Statement. Pediatrics, 109(3):524-525.
30. Cervino A; Hosking, SL; Montes-Mico, R; Bates, K (Jun 2007). "Clinical ocular wavefront analyzers." Journal of refractive surgery (Thorofare, N.J.: 1995) 23 (6): 603–16.PMID 17598581
31. Lawless, MA; Hodge, C (Apr 2005). "Wavefront's role in corneal refractive surgery.". Clinical and experimental ophthalmology 33 (2): 199–209. doi:10.1111/j.14429071.2005.00994.x. PMID15807834.
32. Lombardo, M; Lombardo, G (Feb 2010). "Wave aberration of human eyes and new descriptors of image optical quality and visual performance.". Journal of cataract and refractive surgery 36 (2): 313–31. doi:10.1016/j.jcrs.2009.09.026. PMID20152616.
33. Basic and Clinical Science Course, Section 13: Refractive Surgery (2011-2012. ed.). American Academy of Ophthalmology. 2011–2012.
34. Basic and Clinical Science Course, Section 3: Clinical Optics (2011-2012lastmajorrev. 2010-2012. ed.).

American Academy of Ophthalmology. 2011–2012. p. 100. ISBN978-1615251100pp. 7–9. ISBN 9781615251209.
35. Dimitri T. Azar, Damien Gatinel, Thang Hoang-Xuan (2007). Refractive surgery (2nd ed.). Philadelphia: Mosby Elsevier. ISBN 978-0-323-03599-6.
36. Myron Yanoff, Jay S. Duker (2009). Ophthalmology (3rd ed.). Mosby Elsevier. p. 104. ISBN 978-0-323-04332-8
37. Wyant, James C. "Zernike Polynomials".
38. Hong – Zin Lin, Chein – Chung Chen, Yuan- Cheih Lee " Comparison of wave front, Autorefraction and Subjective Refraction" Tzu medical journal 25(2013) 43-46.
39. Lebow K A, Campbell C E. A Comparison of a Traditional and WavefrontAutorefraction. Optometry and Vision Science 2014;91:00-00
40. Bennett J R, Stalboergera G M, Hodgeb D O, Schornacka M M. Comparison of refractive assessment by wave frontaberrometry, autorefraction, and subjective refraction.Journal of Optometry (2015) 8, 109-115
41. McCullough S J, Little J A, et al. Comparison of Refractive Error Measures by theIRX3 Aberrometer and Autorefraction. Optometery and Vision Science. Vol. 91, No. 10, 1183-1190.

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