Measurement of Accommodative Amplitude Using Wavefront Aberrometer

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ABSTRACT

Objective: To measure and compare the accommodative amplitude of Filipino patients with different accommodative conditions using a wavefront aberrometer.

Methods: A total of 120 eyes of 67 patients seen in a private eye center were included and divided into two groups (phakic and pseudophakic). After undergoing routine ophthalmologic examination that included manifest refraction and visual acuity testing, accommodative amplitude was measured using the iTrace™ wavefront aberrometer. Comparison of the measurements was made between the accommodative amplitude of phakic pre-presbyopes and presbyopes, and between eyes implanted with monofocal and accommodating intraocular lenses (IOLs).

Results: The mean age of the pre-presbyopes was 27 years, presbyopes 50 years, monofocal IOL 69 years, and accommodating IOL 67 years. The mean accommodative amplitude of the pre-presbyopes was 1.64 ± 1.06D, presbyopes 0.99 ± 0.42D, monofocal IOL 0.36 ± 1.16D, and accommodating IOL 0.94 ± 0.89D. The pre-presbyopes had a higher accommodative amplitude than the presbyopes (p=0.008), while the accommodating IOL subgroup had a higher amplitude than the monofocal IOL subgroup (p=0.02). Increasing age was correlated with decreasing amplitude in the phakic group (r^2=0.926). There was no correlation between refractive error and amplitude of accommodation in the phakic and pseudophakic groups (r^2=0.02 for both groups).

Conclusion: The wavefront aberrometer is a reliable tool in objectively measuring accommodative amplitude. Pre-presbyopes and accommodating IOLs were shown to have higher amplitudes of accommodation than presbyopes and monofocal IOLs.

Keywords: wavefront aberrometer, accommodative amplitude, presbyopia, accommodating intraocular lens, monofocal intraocular lens

An individual less than 40 years of age can see near objects with ease because their natural lens still has strong accommodative capabilities.[1-3] Beyond age 40, presbyopia and cataracts, which are both age-related causes of visual impairment, will eventually set in. Presbyopia is the decline in accommodation that leads to the reduced ability of the eye to focus on near objects. It is theorized that stiffening of the lens is the primary mechanism for presbyopia.[4,5] This process usually becomes noticeable between ages 40 and 50 and increases with age, necessitating use of corrective lenses.[6]

Cataract, which is the top cause of blindness worldwide in 2010,[7] is formed by the compression and hardening of the lens with advancing age, leading to change in its refractive index, resulting in scattering of light.[1] These changes cause blurred and reduced vision, faded color perception, glare, light sensitivity, and impaired night vision.[1] During cataract surgery, the cataractous lens is removed and replaced with an intraocular lens which can be monofocal, multifocal, or accommodating. Monofocal and multifocal intraocular lenses (IOLs) are fixed lenses presumed to have no accommodating capabilities.[8,10] On the other hand, accommodative IOLs were designed to simulate the accommodative properties of the natural crystalline lens.[11,12] In a study on eyes implanted with 1CU® (Human Optics, Germany) accommodating IOL, accommodative amplitudes reached up to 2.0 diopters (D) using an autorefractor.[13] However, in a study on Crystalens® (Bausch & Lomb, New York, USA) accommodating IOLs, the accommodative amplitudes were lower than 0.4 D in all subjects measured by a custom-developed aberrometer.[14] These results were inconsistent as a result of the investigators using different methods to measure accommodation.[15,16]

Accommodation has often been measured clinically using the push-up test, in which the subject focuses at a given line of text through his distance correction and is instructed to indicate when the object is moved close enough to blur the line.[16] Investigations of changes in maximum accommodation with age date back to the late 1800s with studies performed by Donders who measured accommodation in 130 individuals between the ages of 10 and 80 years, using a variation of the subjective push-up technique.[17] Duane presented similar data, showing decrease of accommodation with age.[18] However, data on both studies presenting the norms of accommodative amplitude with age were based on the push-up technique which is subjective and does not unequivocally measure accommodation.

Recently, there have been studies comparing subjective (push up technique, minus lens blur, push down, defocus) and objective [Hartinger Coincidence Refractometer (HCR) (Carl Zeiss Meditec, Germany), Grand Seiko autorefractor (Grand Seiko Co., Ltd, Japan), and iTrace™ aberrometer (Tracey Technologies, USA)] methods of measurement.[16,19-23] Results showed that the subjective methods overestimated the amplitude of accommodation, especially in the presbyopic population. Therefore, subjective tests performed on presbyopic patients may lead to erroneous conclusions. Due to a high disparity in the methods that are used, there is significant discrepancy in the results of many studies.

A non-contact ray tracing wavefront aberrometer, such as iTrace™, designed to objectively measure amplitude of accommodation, was shown to yield reproducible results.[14] Aberrometry uses wavefront sensing, which is a technique of measuring the complete refractive status of an optical system.[19] The iTrace™ aberrometer is based on the principle of ray tracing, which is a two-step, serial technique that uses forward projection. The ray tracing method uses a laser beam parallel to the line of sight through the pupil and measures the exact location where the laser beam reaches the retina by means of the retro-reflected light captured by reference lineal sensors.[24] It then integrates these retinal spot positions to measure overall visual performance. It measures high and low order aberrations while the patient is looking at different targets separately. Through its open field measurement, it can determine the patient's wavefront at two fixation points, namely distance and near fixation. This gives the subject the ability to look far away through the instrument, and the examiner to present stimuli at different distances to measure the subject's accommodation power.[24] Comparison of the two wavefronts at these two fixation points yields the accommodative amplitude. In clinical practice, it is obtained through a calibrated stick in which the observer can see the specific distance at which the stimulus is presented. The differences between the refractive maps can be analyzed both in quantitative and qualitative values. The quantitative values are shown as the myopic change given by the accommodation power.[24] Figure 1 shows an example of the iTrace wavefront comparison display presenting the refractive map during near and far fixations separately. The refraction difference map shows the accommodative amplitude of the patient.
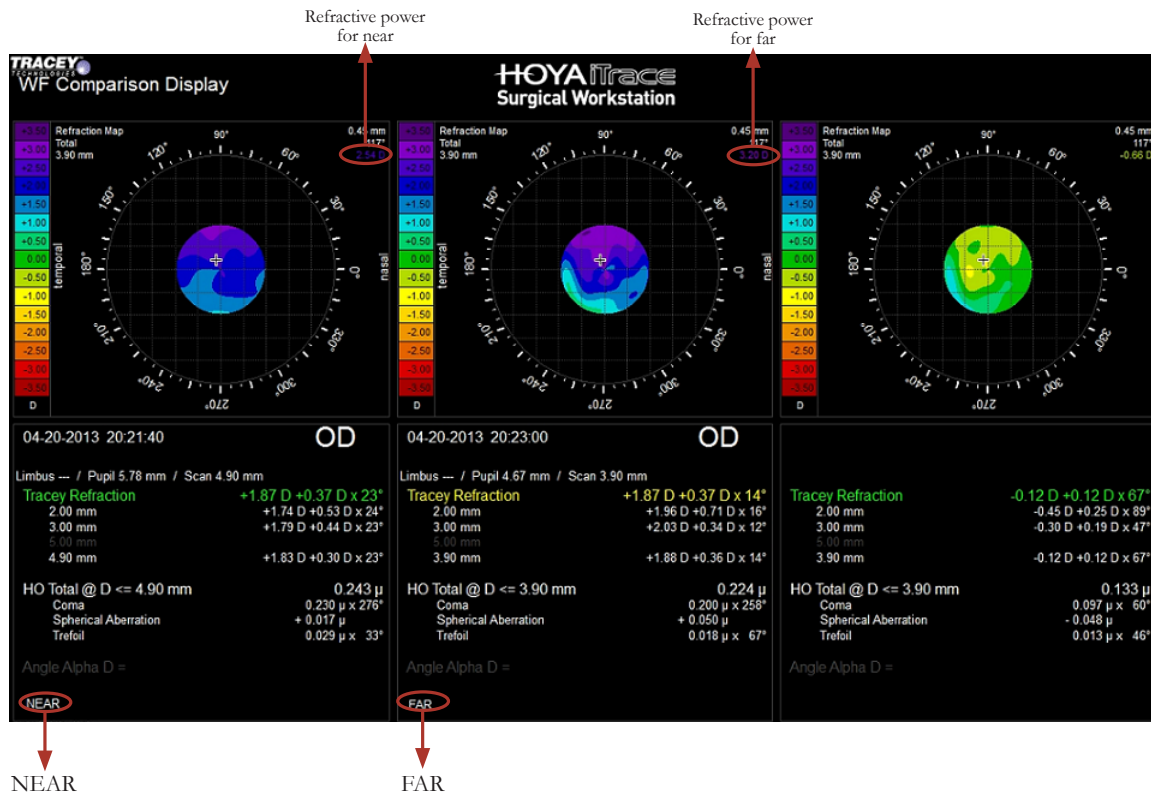
Figure 1. The iTrace™ aberrometry map showing the near (leftmost), far (middle), and the refraction difference (rightmost) maps. Refractive power for near and far fixation are shown separately in the upper right corner of the corresponding map. The accommodative amplitude is the amount of change in the spherical power when the eye changes focus from a distant to a near target.

This study determined the accommodative amplitude of patients with different accommodative conditions using a wavefront device (iTrace™). Specifically, it compared the accommodative amplitude of phakic pre-presbyopic and presbyopic patients, and those implanted with monofocal and accommodating intraocular lenses (IOL).

METHODOLOGY

This is a prospective, cross-sectional study conducted from June to September 2014 in a private eye center.

Subjects

Phakic patients with no cataract, aged between 20-60 years, and pseudophakic patients above 60 years of age with monofocal or accommodating intraocular lenses bilaterally, were invited to participate in the study. They should have best-corrected distance vision of 20/30 or better. Pseudophakic patients should have had cataract surgery at least 3 months or longer prior to enrolment.

Excluded were patients with any ocular surgery (aside from cataract surgery), ocular abnormalities (diabetic retinopathy, glaucoma, corneal or macular pathology), and intraoperative complications such as posterior capsular rent and zonular rupture.

Informed consent was obtained in accordance with the Declaration of Helsinki and institutionally-approved human subjects protocol.

Procedures

Participants underwent a baseline ophthalmic examination, which included uncorrected distance and near vision, distance-corrected visual acuity, manifest refraction, and measurement of reading adds.

Accommodative amplitude was measured using an iTrace™ ray tracing wavefront aberrometer. The patient was seated with his head stabilized on the instrument chin rest and forehead strapped. Measurement light spot was turned off to eliminate

target confusion. Fogging was disabled. For distance measurement, the room light was turned off to relax accommodation and to obtain as large a pupil as possible. The patient was given an unobstructed view of a distant target 20 feet away and a wavefront measurement was obtained. For near measurement, the room light was turned on and a light attached to the machine was aimed at a reading card held in place by a rod placed 40cm in front of the machine aperture. The eye not measured was occluded. The patient was asked to locate the smallest line in the chart that he could read clearly and asked to focus on that line. When the pupil became constricted to 2 to 3 mm, wavefront measurements were taken.

After 3 measurements each for distance and near, the near reading with the smallest pupil size was chosen to be analyzed against the far reading with the largest pupil size. The software (version 4.2) yielded a difference map providing the accommodative amplitude of the eye (Figure 1).

Statistical Analysis

Mean and standard deviation of accommodative amplitude were determined based on the measurements obtained from the iTrace™ ray tracing wavefront aberrometer. Paired t-test compared the mean amplitude of accommodation among the subgroups. A p value <0.05 was considered statistically significant. Accommodative amplitude correlation with age and refractive error in phakic and pseudophakic eyes were analyzed using linear regression.

RESULTS

One hundred and twenty (120) eyes of sixty seven (67) patients seen in a private eye center participated in the study. Eyes were divided into 2 groups: phakic and pseudophakic. Each group was further subdivided into 2 subgroups and compared. Phakic eyes were divided into prepresbyopic and presbyopic subgroups (Table 1). Group A (prepresbyopic) consisted of 23 eyes of 12 patients, aged 27.5 ± 4.7 years, with mean uncorrected distance visual acuity (UDVA) of 20/125 (logMar 0.8) and mean best-corrected distance visual acuity (BCDVA) of 20/20 (logMar 0). Group B (presbyopic) consisted of 24 eyes of 13 patients, aged 50 ± 6 years, with mean UDVA of 20/80 (logMar 0.6) and mean BCDVA of 20/20 (logMar 0). Differences between the mean UDVA and BCDVA of the two subgroups were not statistically significant (p=0.07). Refractive error of the 2 subgroups was also comparable (p=0.09).

Table 1. Demographic characteristics of phakic patients.

Parameter	Prepresbyopic	Presbyopic	p
Patients (n)	12	13	
Eyes (n)	23	24	
Male: Female	0.5	1.5	
Age (mean +/-SD)	27.5 ± 4.7	50 ± 6	0.0001
Mean Spherical Equivalent	-3.09 ± 2.59	-1.84 ± 2.42	0.09
Mean UDVA	20/125 (logMar 0.8)	20/80 (logMar 0.6)	0.07
Mean BCDVA	20/20 (logMar 0)	20/20 (logMar 0)	0

UDVA – uncorrected distance visual acuity; BCDVA – best corrected distance visual acuity; SD – standard deviation

Pseudophakic eyes were subdivided into those implanted with monofocal and accommodating IOLs (Table 2). Group C (monofocal IOL) consisted of 28 eyes of 16 patients, aged 69 ± 12 years, with mean UDVA of 20/30 (logMar 0.15) and mean BCDVA of 20/20 (logMar 0.03). Sixteen (16) eyes were previously implanted with Acrysof® (Alcon Laboratories, Inc, Texas, USA), 6 with Akreos™ (Bausch and Lomb, Inc. New York, USA), 1 with Softec (Lenstec, Florida, USA), 1 with Envista MX60 (Bausch and Lomb, Inc. New York, USA), and 4 with unspecified brand of monofocal IOLs. Group D (accommodating IOL Crystalens®) (Bausch and Lomb, Inc. New York, USA) consisted of 45 eyes of 26 patients, aged 67 ± 12 years, with mean UDVA of 20/20 (logMar 0.07) and BCDVA of 20/20 (logMar 0.03). Age, refractive error, and mean postoperative duration of the two subgroups were comparable (p=0.28, 0.22, and 0.09, respectively). Uncorrected visual acuity of those with accommodating IOL was better than those with monofocal IOL (p=0.04), while the mean best-corrected distance visual acuity was similar for the 2 subgroups (p=0.35).

Table 2. Demographic characteristics of pseudophakic patients.

Parameter	Monofocal IOL	Accommodating	p
Patients (n)	16	26	
Eyes (n)	28	45	
Male: Female			
Age (mean +/-SD)	69 ± 12	67 ± 12	0.28
Mean Spherical Equivalent	-0.24 ± 0.84	-0.44 ± 0.58	0.22
Mean Postoperative duration (months)	36	27	0.09
Mean UDVA	20/30 (logMar 0.15)	20/20 (logMar 0.07)	0.04
Mean BCDVA	20/20 (logMar 0.03)	20/20 (logMar 0.02)	0.35

UDVA – uncorrected distance visual acuity; BCDVA – best corrected distance visual acuity; SD – standard deviation

Accommodative Amplitude of Phakic Eyes.

The mean accommodative amplitude of pre-presbyopic eyes is 1.64D, significantly larger than the 0.99D measured in presbyopic eyes (Table 3). Linear regression showed a positive correlation (r^2=0.926) between age and accommodative amplitude in phakic eyes (Figure 2). There was no observed correlation between refractive error (spherical equivalent) and accommodative amplitude in phakic eyes (Figure 3).

Table 3. Comparison of accommodative amplitude of the different subgroups using wavefront aberrometer.

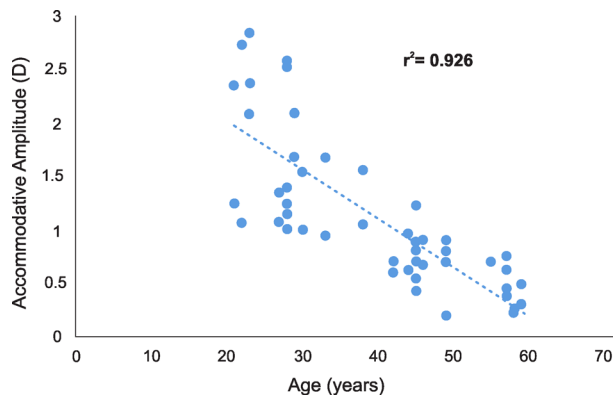| Subgroup	Accommodative Amplitude Mean (SD)	p
Prepresbyopes Presbyopes	1.64 ± 1.06D 0.99 ± 0.42D	0.008
Monofocal IOL Accommodating IOL	0.36 ± 1.16D 0.94 ± 0.89D	0.02

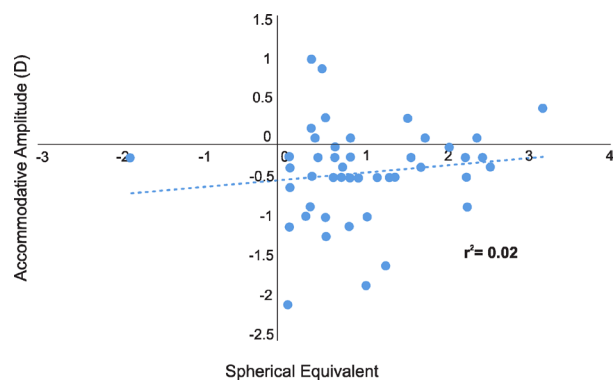**Figure 2.** Relationship between age and accommodative amplitude in phakic eyes.

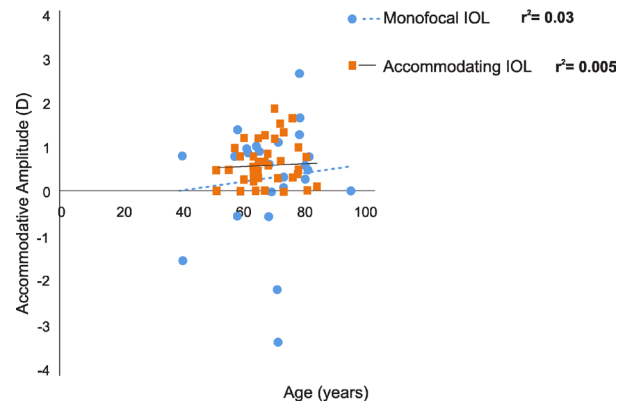**Figure 3.** Relationship between spherical equivalent and accommodative amplitude in phakic eyes.

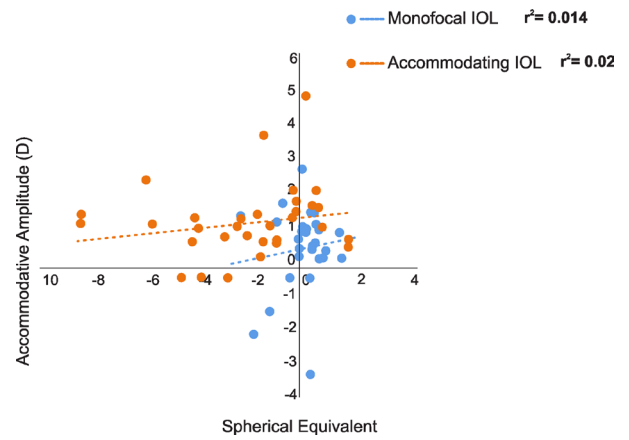**Figure 4.** Relationship between age and accommodative amplitude in pseudophakic eyes.

Figure 5. Relationship between spherical equivalent and accommodative amplitude in pseudophakic eyes.

Accommodative Amplitude of Pseudophakic Eyes.

The mean accommodative amplitude of eyes implanted with accommodating IOLs was 0.94D, significantly higher than the 0.36D seen in eyes implanted with monofocal IOLs (Table 3). Accommodative amplitude of eyes with monofocal and accommodating IOLs did not show any correlation with age (Figure 4) nor refractive error measured as spherical equivalent (Figure 5).

DISCUSSION

The limitations of subjective methods, such as push-up techniques in measuring accommodative amplitude, are well-documented in several studies.[16,20-25] An objective measuring device is essential to provide accurate normative values. Clinical studies of intraoc-

Table 4. Comparison of different accommodative amplitude testing.

Study (Authors, Year)	Participant Description	Mean Age ± SD (Range)	No. of eyes (n)	Refractive Errors	Type of IOL	Type of measurement	Method of Measurement	Accommodative Amplitude	Comments
Langen-bucher, Huber, et al, 2003[13]	Accommo-dating pseudophakic eyes	(41 to 87 years)	23	Not mentioned	1CU® (Human Optics, Germany)	Subjective	NPA Defocus	1.60 ± 0.55 inches 1.46 ± 0.53 D	Subjective methods overestimated AOA in accommo-dating IOLs
						Objective	Power Refractor Retinoscopy	1.00 ± 0.44 D 0.99 ± 0.48 D	
Wold, Hu, et al, 2003[20]	Phakic pre-presbyopic eyes	(23 to 36 years)	30	+2 to -2 D sphere; <+0.50D cylinder	N/A	Subjective	Minus-lens-blur	7.02 ± 2.00 D	Subjective measures overestimated true AOA
						Objective	HCR	5.05 ± 3.05 D	
Ostrin, Glasser, 2004[21]	Phakic pre-presbyopic eyes	43.7 years (31 to 53)	31 (Distri-bution of subjects not men-tioned)	Not mentioned	N/A	Subjective	Push-up Minus-to-blur Focometer	7.64 ± 1.88 D 4.4 ± 1.61 D 4.35 ± 1.65 D	Subjective methods over-estimated AOA, especially in presbyopic population
						Objective	HCR with trial lens HCR with pilocarpine	4.88 ± 2.41 D 5.60 ± 1.18	
	Phakic presbyopic eyes				N/A	Subjective	Push-up Minus-to-blur Focometer	3.04 ± 1.16 D 1.24 ± 0.58 D 1.83 ± 0.53 D	
						Objective	HCR with trial lens HCR with pilocarpine	0.62 ± 0.32 D 1.10 ± 0.46 D	
Wolffsohn, Hunt, et al, 2006[25]	Accommo-dating pseudophakic eyes	60.7 ± 15.4 years (33 to 78)	20	0.71 ± 0.44-D (spherical equivalent)	1CU® (Human Optics, Germany)	Subjective	RAF rule	2.24 ± 0.42 D	Subjective measures overestimated AOA in accommodating IOL.
						Objective	AutoRefractor PowerRefractor	0.32 ± 0.23 D 0.72 ± 0.38 D	
Win-Hall, Ostrin, 2007[22]	Phakic prepresbyopic eyes	(21 to 30 years)	22	+ 2.75 to − 5.75 D sphere; 0 to -1.75 D cylinder	N/A	Subjective	Push-up	7.74 ± 0.36 D	Subjective push-up test overestimated AOA relative to objective measures in phakic prepresbyopic eyes
						Objective	Grand Seiko HCR	4.68 ± 0.10 D 4.13 ± 0.09 D	
Win-Hall, Glasser, 2008[26]	Phakic pre-presbyopic eyes	41.2 ± 2.98 years	30	+1.00 to -8.50 D sphere; 0 to -1.75 D cylinder	N/A	Subjective	Push-up	4.76 ± 1.32 D	Both devices suitable for objective measurement of AOA in phakic prepres-byopic population
						Objective	Grand Seiko iTrace	2.91 ± 1.01 D 2.90 ± 0.99 D	
Win-Hall, Glasser, 2009[23]	Pseudophakic eyes	66.2 ± 11.23 years	20	-2.48 ± 4.06 D (+4.36 to -7.55D) sphere; -0.35 ± 0.15D cylinder	Monofocal IOL	Subjective	Push-down Defocus	3.28 ± 1.11 D (OD) 3.64 ± 1.68 D (OS) 2.00 D	Subjective push-up test overestimated AOA relative to objective measures in pseudophakic eyes
						Objective	Grand Seiko iTrace	0.11 ± 0.50 D 0.10 ± 0.47 D	
Wolffsohn, et al, 2010[27]	Accommo-dating pseudophakic eyes	68.4 ± 11.7 years (45 to 81)	13	Not mentioned	Tetraflex (Lenstec, Florida, USA)	Objective	AutoRefractor	0.2 ± 0.3 D	
Win-Hall, Houser, et al, 2010[28]	Phakic pre-presbyopic eyes	23.8 ± 0.58 years (20 to 28)	30	Not mentioned	N/A	Objective	Grand Seiko	5.00 D	
Perez-Merino, et al, 2014[14]	Phakic pre-presbyopic eyes	28 ± 4.0 years (21 to 34)	17	-0.2 ± 0.6 D spherical equivalent	N/A	Objective	Custom-developed aberrometer	0.79 ± 0.25 D	AOA of patients with accommodating IOL limited; pseudo-accommo-dation from increased DOF contributed to near vision functionality
	Accommo-dating pseudophakic eyes	75 ± 4.0 years (67 to 81)	22	-0.5 ± 0.4 D spherical equivalent	Crystalens® (Bausch & Lomb, NY,	Objective	Custom-developed aberrometer	0.03 ± 0.33 D	
Sarmiento, Ang, et al, 2015	Phakic pre-presbyopic eyes	27.5 ± 4.7 years	23	-3.09 ± 2.59 D spherical equivalent	N/A	Objective	iTrace	1.64 ± 1.06 D	
	Phakic presbyopic eyes	50 ± 6.0 years	24	-1.84 ± 2.42 D spherical equivalent	N/A			0.99 ± 0.42 D	
	Monofocal pseudophakic eyes	70 ± 12.0 years	28	-0.24 ± 0.84 D spherical equivalent	Standard monofocal IOL			0.36 ± 1.16 D	
	Accommo-dating pseudophakic eyes	67 ± 12.0 years	45	-0.44 ± 0.58 D spherical equivalent	Crystalens® (Bausch & Lomb, NY, USA)			0.94 ± 0.89 D	

IOL – intraocular lens; HCR – Hartinger coincidence refractometer; OD – Right eye; OS – Left eye; NPA – near point of accommodation; RAF – Royal Air Force; DOF – depth of focus; AOA – amplitude of accommodation

ular lenses which promise to restore accommodation in presbyopic eyes should utilize objective methods of measurement for reliability and reproducibility of results. This study investigated the ability of a commercially available wavefront aberrometer (iTrace) to objectively measure the accommodative amplitude of phakic and pseudophakic Filipino patients.

Table 4 shows the different studies from 2003 to 2015 comparing the different testing methods for accommodative amplitude. In a study by Win-Hall et al,[26] the mean accommodative amplitude of prepresbyopic eyes was 2.90 ± 0.99D using the iTrace™ aberrometer. This value was significantly higher than the measured mean accommodative amplitude of 1.37 ± 1.09D in prepresbyopic eyes in our study using the same device. Our value using the iTrace aberrometer was higher compared with the measurement of 0.79 ± 0.25D obtained using a custom-developed aberrometer,[14] lower than the 5.0D with the Grand Seiko autorefractor,[22,23] and lower than the 4.13 ± 0.09D obtained from the Hartinger coincidence refractometer.[22] We tabulated the published reports to demonstrate the variability of outcomes using different devices because there is no concensus yet which is the better device to measure accommodative amplitude. Nevertheless, our study is relevant because we compared the prepresbyope to a presbyopic subgroup and we were able to demonstrate the expected decline of accommodative amplitude with increasing age.

Another important aspect of our study is the comparison of monofocal to accommodating intraocular lenses which has not been reported previously. In our study, eyes implanted with monofocal intraocular lenses showed mean accommodative amplitude of 0.36 diopters. Our measurement was similar to that observed in the previous study,[23] which compared the accommodative amplitude of eyes with monofocal IOLs using iTrace™ aberrometer and Grand Seiko autorefractor.

Our study showed that eyes with the Crystalens® accommodating IOLs achieved a mean accommodative amplitude of 0.94 diopters. Our results were significantly higher compared to the value obtained from a recent study that measured accommodative amplitude in 22 eyes implanted with Crystalens® accommodating IOL using a custom-developed aberrometer.[14] Compared to monofocal intraocular lenses, Crystalens-implanted eyes were expected, and shown by our results, to have a higher accommodative amplitude.

We analyzed the effect of refractive error on accommodation measurements. In a study by Abraham et al,[29] they found that accommodative amplitude was higher in myopic eyes as compared to emmetropes and hypermetropes. In another study by McBrien et al,[30] it was shown that late onset myopes have the largest amplitude of accommodation, as measured by near point rule. Our subjects were mostly myopic. However, we could not find a relationship between the refractive error and the accommodative amplitude in the phakic (r^2 = 0.02), monofocal (r^2=0.014), and Crystalens-implanted eyes (r^2=0.02).

There is currently no established gold standard for measuring accommodative amplitude. The results in this study were compared to published results using different devices. Comparing different objective measures of accommodative amplitude in the same study population would provide a clearer picture of the amount of accommodation in different eye conditions.

In summary, the iTrace™ ray tracing wavefront aberrometer was able to objectively measure the differences and demonstrate the higher accommodative capabilities of prepresbyopes over presbyopes and accommodating over monofocal intraocular lenses. It can be a useful tool for accurate prescription of reading glasses, measuring residual accommodation to ascertain suitability for presbyopic treatments, and assessing the accommodative properties of certain IOLs.

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