

Original research

Optical aberrations, accommodation, and visual acuity with a bioanalogic continuous focus intraocular lens after cataract surgery

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Abstract

Purpose: To evaluate the visual outcomes, pseudoaccommodation, and wavefront aberrometry after implantation of Wichterle IOL-Continuous Focus (WIOL-CF[®], Gelmed International, Kamenne Zehrovice, Czech Republic) by i-Trace aberrometry.

Methods: In this retrospective interventional case series study, after cataract surgery with implantation of accommodative WIOL-CF[®], the patients were evaluated with i-Trace aberrometer for measurement of modulation transfer function (MTF), point spread function (PSF), total aberrations, higher order aberrations (HOAs) at far and near and pseudoaccommodation. The pre and postoperative visual acuity at near and distance were also measured.

Results: Forty eyes of 20 patients (aged 40–77 years) were enrolled in this study with mean follow-up time of up 13.10 ± 5.52 months. The mean logMAR corrected distance visual acuity (CDVA) improved from 0.20 ± 0.14 preoperatively to 0.10 ± 0.09 at the last follow-up after surgery ($P = 0.002$). The results were 60% J1, 70% J2, 85% J3, 90% J4, 95% J5 and 100% for J6. The mean pseudoaccommodation, range of accommodation volume, and average of peak accommodation were -2.52 ± 1.56 diopters (D), 1.50 to 5.25 D and -3.25 ± 1.25 D, respectively. The mean MTF at 5 cycles per degree at far was 0.200 ± 0.10 and for near was 0.207 ± 0.10 . PSF at far and near was 0.0002 and 0.001, respectively. The mean root mean square (RMS) value of HOAs; total, coma spherical aberration, trefoil, and secondary astigmatism were $1.08 \pm 0.48 \mu\text{m}$, $0.89 \pm 0.45 \mu\text{m}$, $-0.33 \pm 0.23 \mu\text{m}$, $0.25 \pm 0.17 \mu\text{m}$, and $0.15 \pm 0.13 \mu\text{m}$ for far and $0.88 \pm 0.49 \mu\text{m}$, $0.73 \pm 0.46 \mu\text{m}$, $-0.25 \pm 0.22 \mu\text{m}$, $0.19 \pm 0.16 \mu\text{m}$ and $0.11 \pm 0.10 \mu\text{m}$ for near, respectively. There was a decrease in HOAs at near relative to far ($P < 0.05$).

Conclusion: WIOL-CF[®] seems to be an acceptable accommodative intraocular lens (IOL) in terms of uncorrected near and distant visual outcomes, MTF and HOA.

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Keywords: Pseudoaccommodation; Higher order aberrations; Wichterle IOL-Continuous Focus implantation

Introduction

There are numerous acceptable modalities to compensate for post-cataract surgery near vision including monovision, multifocal, and accommodative intraocular lenses (IOLs).¹

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The major drawback of using the monovision technique is the problems with stereopsis and binocular vision.² Regarding such difficulties, multifocal IOLs were introduced as an alternative option. The goal of using multifocal IOLs is to provide the patients with satisfactory vision for both near and distant targets and create a range of clear vision at intermediate; however, the lack of good quality vision and limitations such as decrease in contrast sensitivity, halo, and night glares are the major concerns in implantation of multifocal IOLs.³

Another treatment modality for correction of presbyopia after phacoemulsification is using accommodative IOLs that offer acceptable vision for targets at different distances by

restoring part of accommodation. Currently, there are multiple options as accommodative IOLs; Diffractiva® (Human Optics, Germany), BioComFold (Morcher, Germany), AT-45 Crystallens (Eyeonics, Inc., Bausch & Lomb, Rochester, NY, USA), and a newer generation of Crystallens HD (Bausch & Lomb, Rochester, NY, USA).³ The most important limitation in implantation of accommodative IOLs is reduction of accommodative capacity in the course of postoperative period, that is largely due to formation of adhesive bands between anterior and posterior capsule and capsular phimosis that restrict their presumed accommodative ability.⁴

Wichterle and his colleagues designed a newfangled accommodative IOL, so-called Wichterle IOL-Continuous Focus (WIOL-CF®), a polyfocal hydrogel IOL.⁵ The changes in anterior–posterior position of the IOL resulting from contraction of ciliary muscle or vitreous pressure and its multiple focal points with alterations in lens curvature and refractive power are mainly the source of accommodative capacity of this implant.^{6,7}

There are multiple studies in literature regarding visual outcomes and stability of implantation of WIOL-CF® (Gelmed International, Kamenne Zehrovice, Czech Republic) and qualitative assessment of dysphotopic phenomena.^{7–9}

Herein, we report visual and quantitative optical outcomes of WIOL-CF® implantation in a group of patients in terms of near and far visual acuities, the range of pseudoaccommodative function, modulation transfer function (MTF), point spread function (PSF), total aberrations, and higher order aberrations (HOAs) by i-Trace technology.

Methods

In this retrospective interventional case series, patients who underwent uncomplicated phacoemulsification and WIOL-CF® implantation from 2011 to 2013 were enrolled.

Exclusion criteria included corneal astigmatism higher than 1.00 diopter (D), amblyopia, corneal diseases (dystrophy, scar or endothelial diseases), retinal and optic nerve problems, previous refractive or intraocular surgery other than phacoemulsification, uveitis and inflammatory ocular disease, history of ocular trauma, incomplete or damaged zonula, intra and postoperative complications including vitreous loss, Descemet's membrane detachment and pseudophakic bullous keratopathy.

Surgical technique

An experienced surgeon (M.M.) performed cataract surgery for all patients using standard technique of phacoemulsification through a 2.8 mm clear cornea temporal incision and a 5.5–6.5 mm centered capsulorhexis. After insertion of WIOL-CF®, cohesive viscoelastic material from behind the lens was cleaned by gentle irrigation. The lens was pushed gently down and inside of the posterior capsular bag for 5 s in order to achieve proper adhesion of IOL to the capsule and prevention of IOL decentration. At the end of surgery, the anterior chamber was formed by hydration of the incision sites.

Preoperative biometric measurement and IOL power calculation were performed using Zeiss IOL Master 500 (Zeiss, Jena, Germany) and SRK-T formula for emmetropia.⁵

The outcome variables that were analyzed for all patients included preoperative and postoperative measurement of uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), and postoperative monocular measurement of uncorrected near visual acuity (UNVA) with Snellen chart at 20 feet and Birkhauser card (as well as Jaeger charts at a distance of 40 cm). Distance visual acuity was converted to logMAR for analysis.

In the last follow-up exam, all patients were tested with i-Trace aberrometry (Tracey Technologies Corp., Houston, TX) at far and near. Pupils were dilated for evaluation of MTF, PSF, encircled energy function (EEF); the two-dimensional integral of the PSF, total aberrations, HOAs total, coma, spherical aberration, trefoil and secondary astigmatism. The analysis of MTF and HOA were standardized for 5.0 mm pupil. We also measured pseudoaccommodation which is a phenomenon attributed to gaining near vision without changes in refractive power of the ocular system.⁶

Data were analyzed using non-parametric test (Wilcoxon) and were analyzed by SPSS for windows v22 (IBM Corp Armonk, NY). $P < 0.05$ was considered statistically significant.

Results

Forty eyes of 20 patients were enrolled in this study. The patients' age ranged from 40 to 77 years (mean; 55.31 ± 8.94 years).

The mean logMAR CDVA improved from 0.20 ± 0.14 ($0.00–0.54$) before surgery to 0.10 ± 0.09 ($0.00–0.30$) at the last follow-up that was statistically significant ($P = 0.002$). No loss of line in CDVA happened. Mean follow-up was 13.10 ± 5.52 months with the range of 4–23 months. The results of UNVA were 60% J1, 70% J2, 85% J3, 90% J4, 95% J5, and 100% J6.

The mean pseudoaccommodation, the range of accommodation volume, and average of p accommodation are shown in Table 1. In Fig. 1, wavefront map is shown for estimation of objective pseudoaccommodation in one of the patients.

The mean postoperative MTF at near was increased relative to far, in all spatial frequency except at 15 cycles per degree (cpd). However, these changes were not statistically significant (Table 2).

Table 1
Objective accommodation data analysis.

Parameter	Value
Mean accommodation	-2.52 ± 1.56 diopter
Average peak accommodation	-3.25 ± 1.25 diopter
Range of accommodation volume	1.50–5.25 diopter

Mean accommodation show the average of the myopic shift in the measurement area (pupil); however, it does not have a clinical implication.⁵

Peak accommodation exhibit maximum myopic shift in the lens and control the image location in retina.⁵

Intraocular lens (IOL) flexibility is measured by accommodation volume.⁵

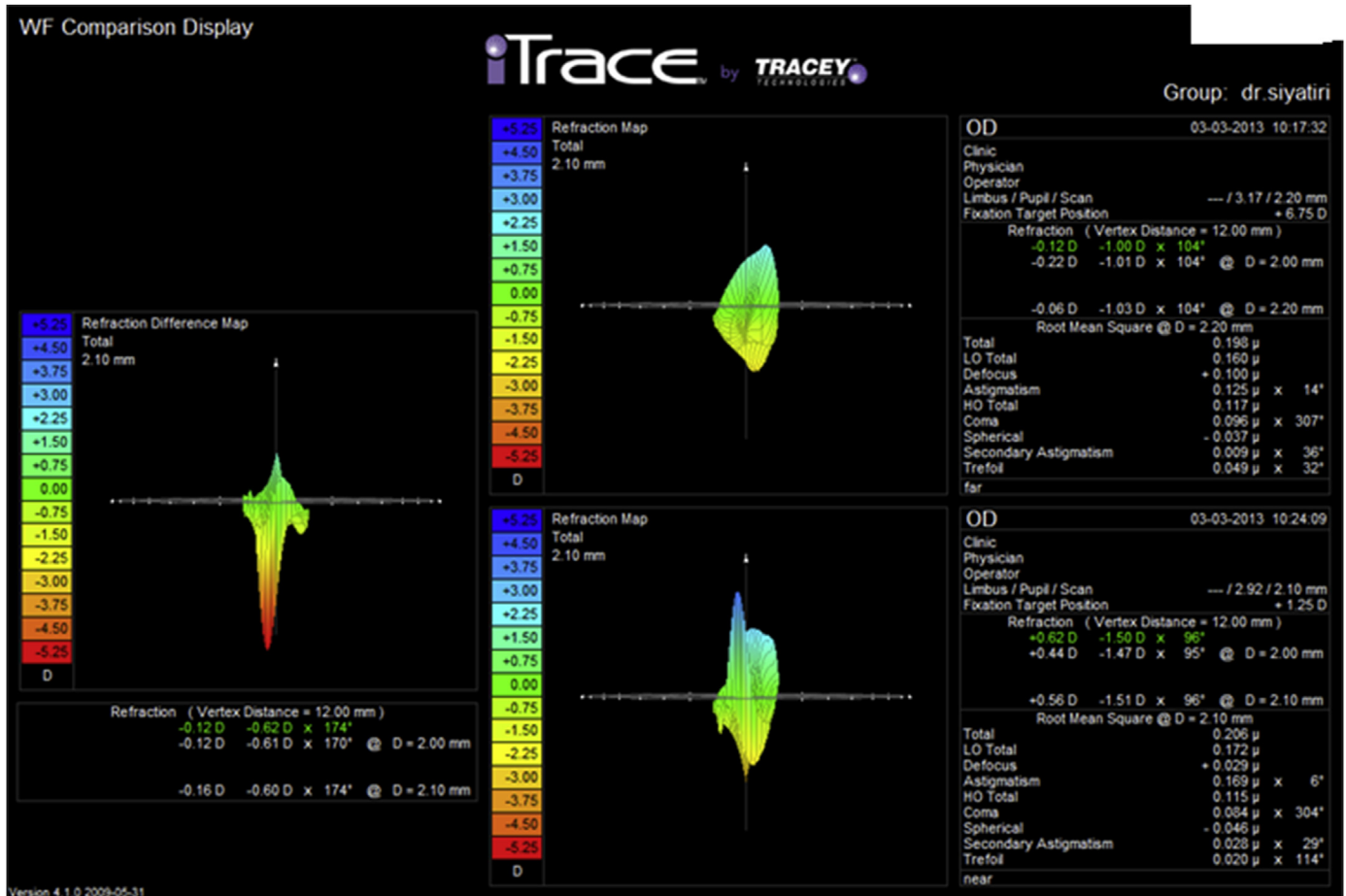


Fig. 1. Measurement of objective pseudoaccommodation by i-Trace.

There was a mean increase in spatial frequency at 5 cpd and then a reduction at moderate to high spatial frequency (Fig. 2).

The range of PSF (we used Strehl ratio that is ideal PSF to aberrated PSF) increased at near, but this change was not statistically significant (Table 2). (Fig. 3). We measured the mean value of EEF by i-Trace aberrometer which was 10.70 ± 5.36 and 9.72 ± 4.64 at far and near, respectively (Table 2) (Figs. 4 and 5).

There was a reduction of total order aberration (TOA) at near that was statistically significant ($P = 0.000$) (Table 2).

The mean root mean square (RMS) value of HOAs, total, coma spherical aberration, trefoil, and secondary astigmatism at far is presented in Table 2. In both far and near there was a mean increase in coma and negative spherical aberration. However, there was a mean decrease in HOAs at near relative to far, that was statistically significant ($P = 0.000$).

Discussion

In this study, our analysis showed the CDVA improved postoperatively with no loss of line of vision in any case. We also found acceptable UNVA; 60% of patients had near vision of J1, 70% J2, 85% J3, 90% J4, and 95% J5 that were comparable with previous studies.^{4,6–8} Therefore, accommodative

WIOL-CF[®] provides satisfactory results for both far and near vision.

In the study of Macsai et al.,¹⁰ uncorrected monocular and binocular near vision was significantly better in the accommodative Crystalens group than the standard monofocal group (95% and 100% vs 15% and 29%, respectively, reading J3 or better postoperatively).

Cumming et al.¹¹ reported uncorrected near vision of J3 or better in 100% of patients with implantation of accommodative Crystalens. In our study, 85% of patients were able to read J3 or better without spectacles that is less in comparison to results of implantation of accommodative Crystalens.^{3–6} However, the mean objective pseudoaccommodation in our study was 2.52 ± 1.56 D that was higher than standard monofocal IOL implantation and is similar to result of WIOL-CF[®] in other studies.^{1,4,6–8} This wide range of pseudoaccommodation resulting from implantation of WIOL-CF[®], provide the patient with an extensive range of clear vision useful in daily tasks.

It is also important to note that the near vision does not correlate to the wide range of pseudoaccommodation in our patients. This can be mainly due to other limiting factors such as pupil size and high order aberrations.

In the study by Win-Hall et al.,¹² objective accommodation measurements in pseudophakia with standard monofocal

Table 2
Wavefront data and comparison the change at far and near.

Wavefront data	Far (Mean ± SD)	Near (Mean ± SD)	Mean difference* (Mean ± SD)	P-value**
Total order aberrations (TOAs)***	2.75 ± 1.66	2.14 ± 1.53	0.61 ± 0.97	0.000
Higher order aberrations (HOAs)*** total	1.08 ± 0.48	0.88 ± 0.49	0.20 ± 0.32	0.000
Coma	0.89 ± 0.45	0.73 ± 0.46	0.15 ± 0.30	0.002
Spherical aberration	-0.33 ± 0.23	-0.25 ± 0.22	-0.08 ± 0.11	0.000
Trefoil	0.25 ± 0.17	0.19 ± 0.16	0.05 ± 0.12	0.012
Secondary astigmatism	0.15 ± 0.13	0.11 ± 0.10	0.03 ± 0.08	0.010
PSF (Strehl ratio)	Min: 0.0002 Max: 0.110	Min: 0.0011 Max: 0.139	-4.195E-3	0.090
MTF (spatial frequency) cycle per degree (cpd)				
5	0.200 ± 0.10	0.207 ± 0.10	-0.007 ± 0.05	0.38
10	0.084 ± 0.04	0.089 ± 0.04	-0.004 ± 0.02	0.26
15	0.065 ± 0.06	0.055 ± 0.02	0.010 ± 0.06	0.3
20	0.040 ± 0.02	0.042 ± 0.02	-0.001 ± 0.01	0.41
25	0.030 ± 0.01	0.033 ± 0.01	-0.002 ± 0.001	0.19
30	0.024 ± 0.01	0.027 ± 0.01	-0.003 ± 0.008	0.27
MTF (average height)	0.139 ± 0.04	0.143 ± 0.04	-0.003 ± 0.016	0.15
EEF	10.70 ± 5.38	9.72 ± 4.64	0.97 ± 3.17	0.059

*: Paired T-test.

** : P-value ≤ 0.05 was considered statistically significant.

***: Root mean square (RMS) (µm).

SD: Standard deviation.

PSF: Point spread function.

MTF: Modulation transfer function.

EEF: Encircled energy function.



Fig. 2. The point spread function (PSF) is used to calculate the encircled energy function (EEF).

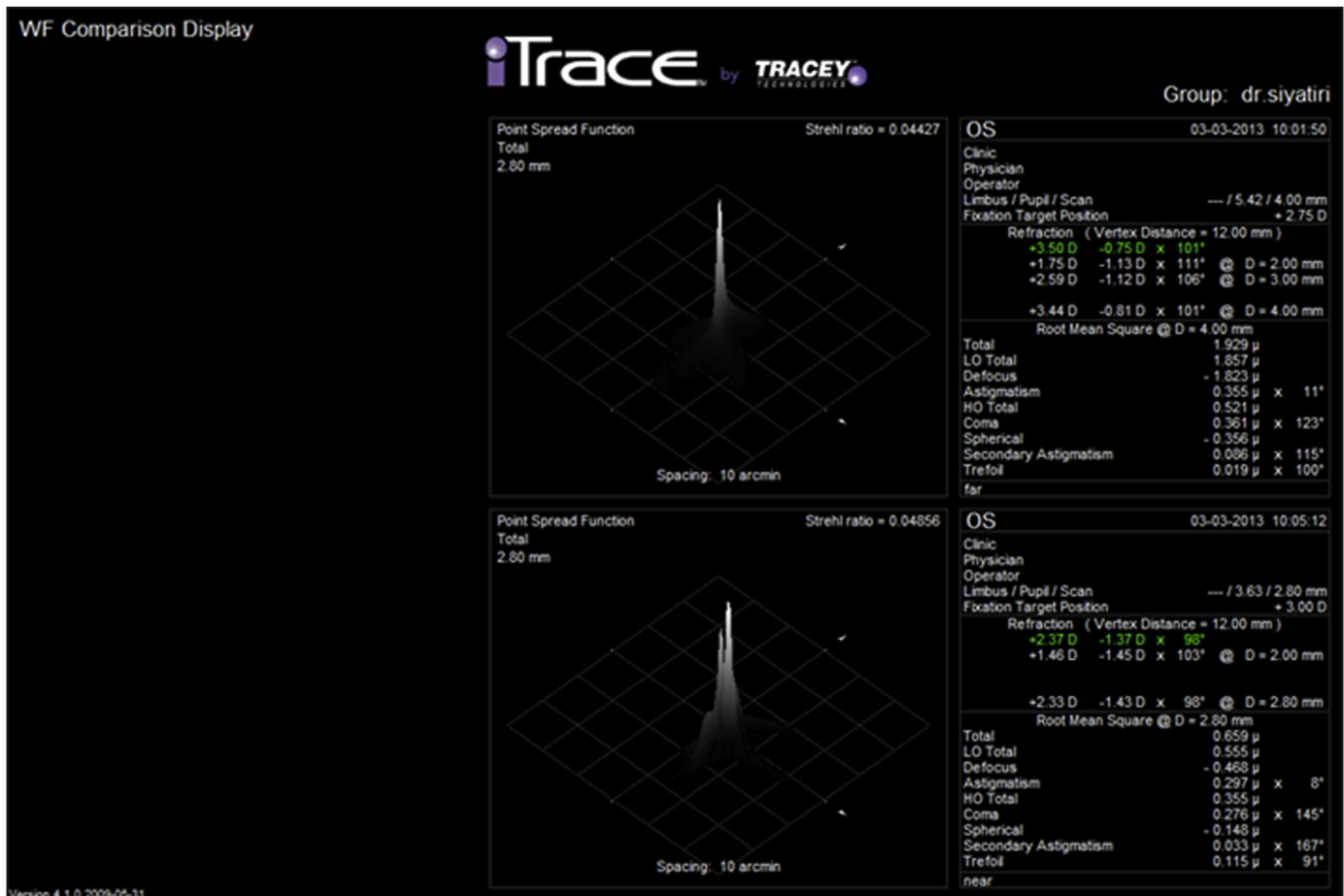


Fig. 3. Point spread function (PSF) total of a patient after cataract surgery and implantation of Wichterle IOL-Continuous Focus (WIOL-CF)[®].

IOLs were 0.11 ± 0.50 D with the auto refractometer and 0.10 ± 0.47 D by the aberrometer. This study has suggested the subjective tests (push-up test, defocus curve, or both) overestimate accommodation amplitude relative to objective measurement because objective tests measure only the dioptric change in the power of the eye, whereas subjective tests measure some complex combination of the effects of ocular aberration, the depth of field of the eye, psychophysical blur perception, as well as any dioptric change in the power of the eye.

We only measured accommodation objectively with i-Trace aberrometer that was shown to be accurate and reliable in previous studies. Wavefront had shown IOL movement resulting from ciliary muscle contraction and increased vitreous pressure, induces myopia associated with spherical aberrations and coma, that are expected beneficial effect at functional near vision.^{4,12–14}

The study of Zamora-Alejo et al. reported that the use of the Crystalens HD provided better intermediate vision compared to monofocal IOLs, but no objective sign of accommodation was demonstrable using an auto refractor during near viewing effort.¹⁵

The MTF defines how an optical system modulates contrast sensitivity and the attenuation of sinusoidal

waveforms as a function of spatial frequency.¹⁶ In our study, MTF was obtained considering the mean value at different spatial frequencies which was less than the pseudophakic eye with monofocal IOLs reported by other studies; however, it was higher than cataractous eyes.¹⁷ The study of Negishik et al.¹⁷ showed that the MTF and the contrast sensitivity of the simulated retinal images in the pseudophakic eyes improved significantly after surgery compared with the cataractous eyes, although both values were less than normal eyes of young peoples.

Another study¹⁶ that evaluated wavefront performance and MTF after bilateral implantation of diffractive (Tecnis and ReSTOR) or refractive (Rezoom) multifocal IOLs showed that the mean MTF value was higher using Tecnis and ReSTOR than Rezoom IOLs, 0.270 ± 0.097 , 0.255 ± 0.112 and 0.109 ± 0.025 , respectively.

In our study, mean MTF (average height, an average modulation between 0 and 30 cycle/degree) was similar to results of Rezoom in a previous study.¹⁶ We also evaluated EEF by i-Trace device.

EEF is an important corollary of the PSF of an optical system and one of the parameters that is associated with point-image quality. It measures the fraction of the total energy in the PSF, which lies within a specified radius 'δ' in the plane of

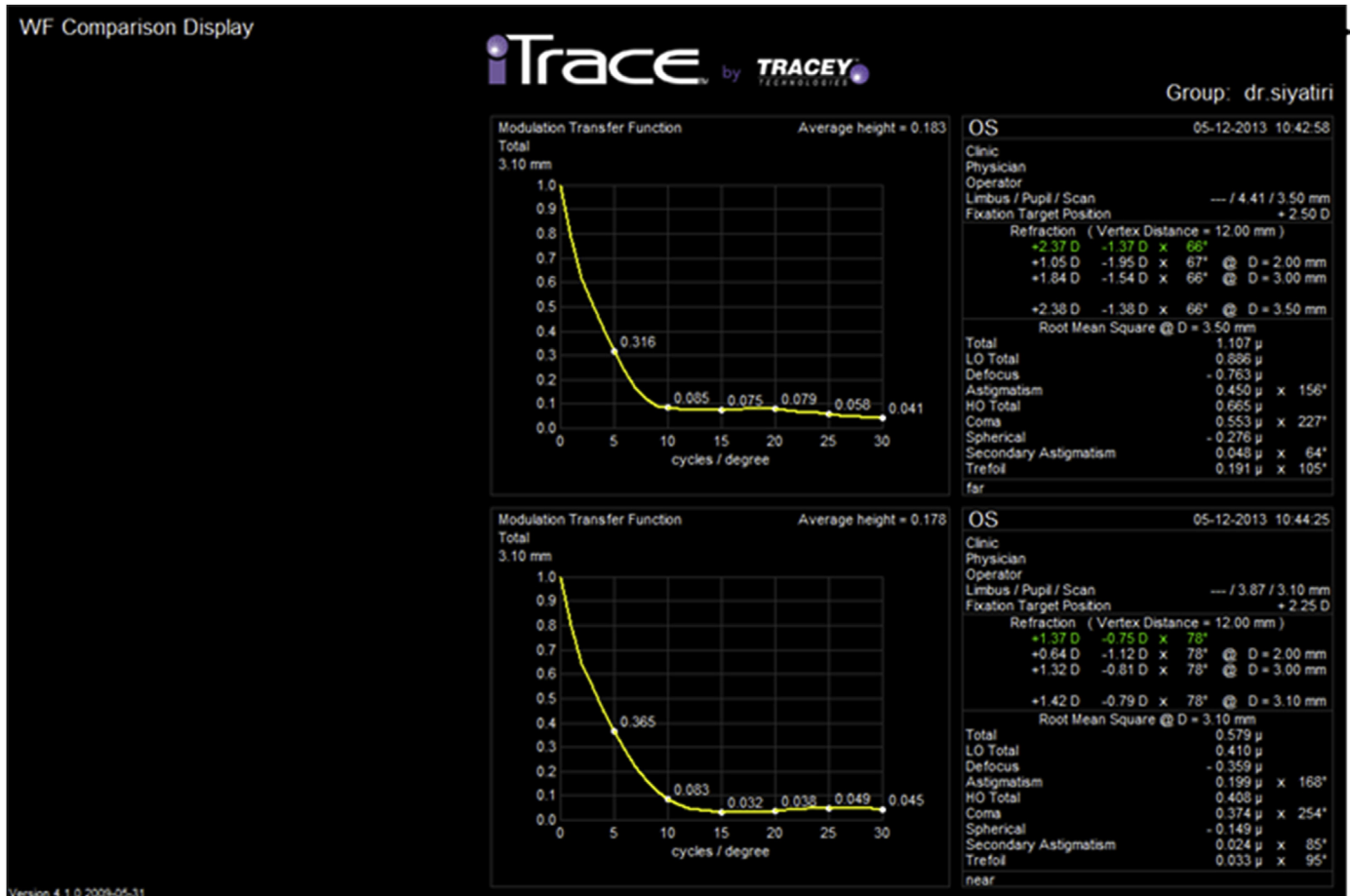


Fig. 4. The mean modulation transfer function (MTF) at variable cycles per degree.

observation or detection. It is a sensible image quality evaluation parameter of an optical system, which may be diffraction-limited, defocused, aberrated, apodised, or even a combined form of all these phenomena.¹⁸

To the best of our knowledge, there is no study that has measured EEF by i-Trace for accommodative WIOL-CF[®]. Therefore, preliminary data of our study will help for future investigations.

In our study, TOA and HOAs are similar to optical aberrations in pseudophakic eye with different IOLs in the study of Vilarrondona¹⁹ that showed total wavefront aberrations of the eye change with the replacement of the crystallin lens by an IOL following cataract surgery. It is typically expected that positive spherical aberration will increase with implantation of a spherical IOL. HOA were significantly higher in the acrylic groups than in the silicon and the polymethyl methacrylate (PMMA) groups. In their study, there were significant differences in the HOA between the acrylic IOLs (refractive index 1.55) and the silicon (refractive index 1.46) and the PMMA (refractive index 1.49) IOLs that suggested the optical aberrations were greater in implantation of IOL with higher refractive indices.

A previous study¹⁶ reported a low spherical aberration in the aspheric IOL compared to a conventional spherical IOL.

Besides that, in accommodative IOLs, the diffractive IOL Tecnis had statistically significant lower values of spherical aberration compared with refractive IOL Rezoom and the mean value of coma-like aberration was lower in Tecnis group compared to the ReSTOR and Rezoom group; however, the differences were not statistically significant.

In our study, we found that optical aberrations reduced at near vision relative to far vision which is expected, probably due to accommodation and perhaps smaller pupil size.

This study has several limitations. The sample size is small, and included both eyes of each patient. We did not evaluate the satisfaction of the patients. Also, our study was not a randomized clinical trial with a control group and postoperative follow-up time was limited. Another major drawback was lack of preoperative wavefront aberration data for comparison.

Therefore, further studies with long-term follow-up are recommended for evaluation of long-term vision limiting factors such as capsular fibrosis and posterior capsular opacification (PCO) and their effect on pseudoaccommodation comparing WIOL with other accommodative and multifocal IOLs.

In conclusion, our results demonstrated an acceptable accommodative capacity of WIOL-CF[®] with good near and

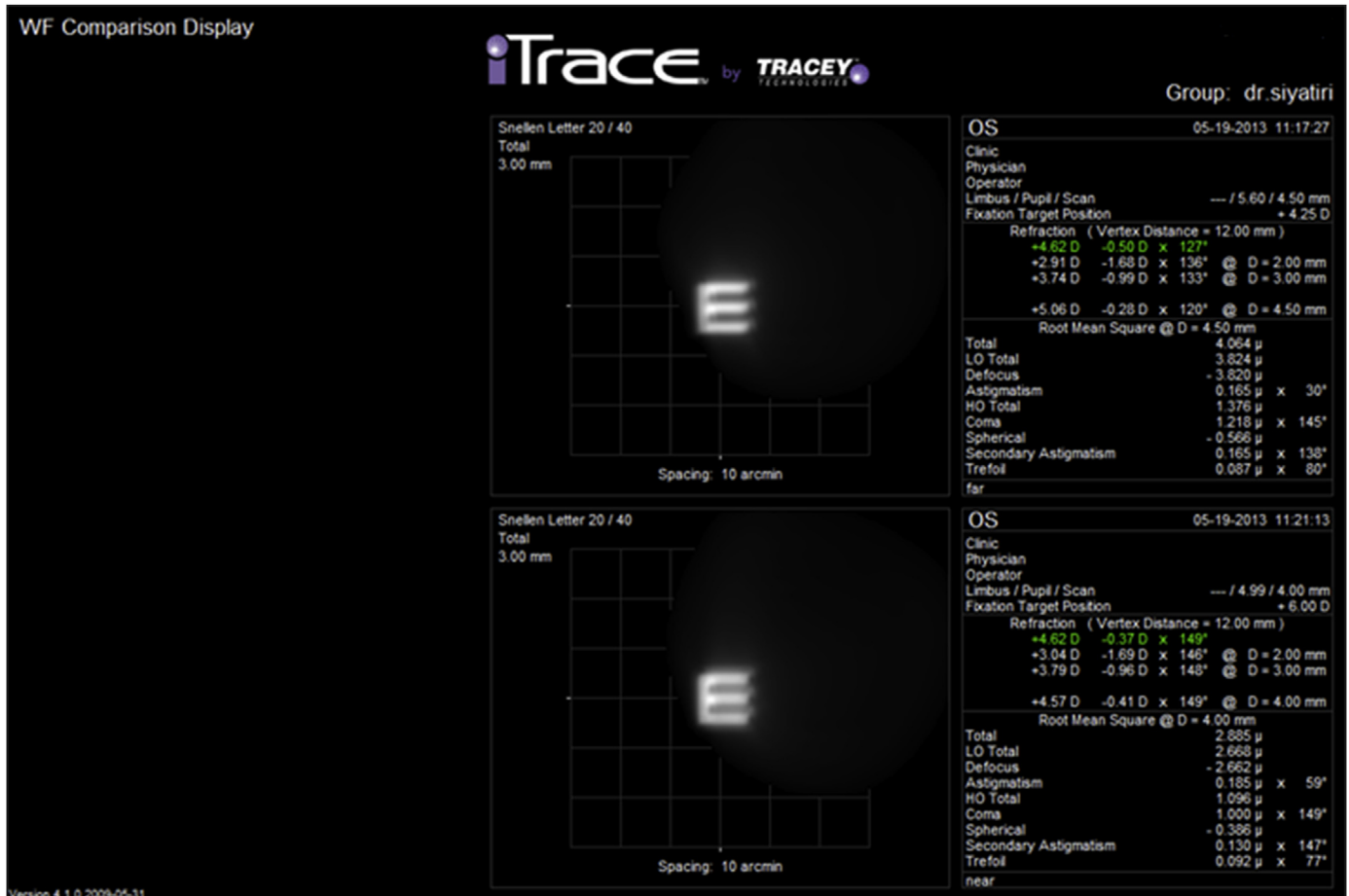


Fig. 5. Simulation of Snellen letter (E) by i-Trace based on an estimate mathematically derived (convolution) from how the eye «would see» the letter «E» projected in different sizes such as 20/20, 20/40, 20/100 and 20/200.

distance visual performance. To the best of our knowledge, this is the first published study on different aspects of WIOL regarding MTF, EEF combined with components of HOA and pseudoaccommodation. This is a pilot study and future well-design studies are needed to draw a definitive conclusion.

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