Comparison of visual outcomes and higher order aberrations of wavefront-optimized and wavefront-guided myopic laser in-situ keratomileusis

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To compare the visual and refractive outcomes of wavefront-optimized (WFO) ablations (wavelight allegretto) and wavefront-guided (WFG) ablations (VISX Custom Vue). Overall, two consecutive groups of eyes were treated for myopia and myopic astigmatism with laser in-situ keratomileusis. One group was treated with WFO ablation and the other group was treated with WFG ablation. Preoperative and 1, 3 and 6 months postoperative refractive evaluation (efficacy, safety, predictability, accuracy, stability, and refractive astigmatism), higher order aberrations (HOAs), and contrast sensitivity were analyzed. The WFO group comprised 20 eyes of 11 patients and the WFG group comprised 34 eyes of 17 patients. Postoperatively, the mean refractive spherical equivalent was –0.21±0.30 D in WFO group and –0.23D±0.57 D in WFG group. The mean values for postoperative uncorrected distance visual acuity were 0.93±0.15 and 0.96±0.16 in WFO and WFG groups, respectively. Safety index was 1.11 in WFO group and 1.17 in WFG group. Six months postoperatively, in WFO group, the induced HOA root mean square (RMS) was 0.25±0.21 μm (P=0.007), induced coma RMS was 0.07±0.23 μm (P=0.84), and induced spherical aberration RMS was 0.03±0.12 μm (P=0.467), whereas induced trefoil RMS was –0.09±0.23 μm (P=0.003). In WFG group, induced HOA RMS was 0.9±0.11 μm (P=0.002), induced coma RMS was 0.01±0.30 μm (P=0.065), and induced spherical aberration RMS was 0.09±0.17 μm (P=0.214), whereas induced trefoil RMS was 0.04±0.15 μm (P=0.005). Contrast sensitivity testing showed a statistically significant improvement in both groups at low spatial frequencies test. Both WFG and WFO showed comparable accuracy, efficacy, and safety with nearly equal induction of all HOA.

Keywords:
aberration, LASIK, refractive surgery, wave front

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Introduction

Excimer laser keratorefractive surgeries such as photorefractive keratectomy and laser in-situ keratomileusis (LASIK) successfully reduce refractive errors. These eliminate lower order aberration (sphere and cylinder) and allow higher order aberration (HOA) to take the upper hand in degrading retinal image quality. Moreover, refractive surgery induces HOAs, and this results in some patients still complaining about glare and halos under dim conditions and poor night vision despite the visual acuity has been raised [1–3].

When laser light contacts the center of the cornea, it is fully absorbed. However, in the periphery, the angle of incidence resulting from the cornea's curved shape may cause energy reflections and losses. Wavefront-optimized (WFO) ablation by allegretto wavelight maintains a more natural corneal shape by adjusting for the asphericity of the cornea based on the anterior curvature readings by placing more pulses in the peripheral area to compensate for energy loss and reflections. This provides a nearly 100% optical zone (true optical zones with a minimized transition zone). At the same time, the natural aspheric shape of the cornea is more preserved and the induction of spherical aberrations is minimized [4,5].

Wavefront-guided (WFG) LASIK may have several proposed advantages over other existing LASIK techniques. Among the proposed benefits is the potential for reducing post-LASIK night-vision problems, which are frequently caused by an increase in the postoperative aberrations. It is believed that WFG LASIK may decrease the amount of induced aberrations and would probably reduce pre-existing

aberrations. The use of small-spot scanning lasers with active eye tracking in WFG ablations may result in the application of larger optical zones with less need for tissue ablation for a given spherocylindrical refractive error, as the ablation was tailored based on mesopic pupil size [6,7].

This study was performed with the aim of evaluation and comparison of the visual and refractive outcomes of WFO versus WFG LASIK.

Study design and methodology

This is a prospective, nonrandomized controlled clinical trial.

The study included two groups of patients whom undergo LASIK surgery

Group 1: WFO included 20 eye of 11pateints for whom LASIK surgery was done using WFO ablation profile of wavelight Allegretto Eye-Q platform.

Group 2: WFG included 34 eye of 17 patients for whom LASIK surgery was done using VISX STAR S4/IR platform.

Inclusion criteria

The following were the inclusion criteria: myopia up to 6 D, myopic astigmatism up to 4 D, and age older than 18 years.

Exclusion criteria

The following were the exclusion criteria: high myopia over 6 D, eyes with keratoconus or irregular astigmatism as proved by corneal topography and Pentacam, eyes with corneal thickness less than 500 µm, previous corneal refractive surgery, corneal scars, history of recurrent herpetic eye disease, patients with glaucoma, cataract, uveitis or any posterior segment abnormality, pregnant or lactating women, and complicated cases during surgery.

The study was conducted between 2013 and 2015 at Roayah Vision Correction Centers.

The study protocol was approved by the Ethics Committee of the Faculty of Medicine, Assuit University.

Preoperative evaluation

Complete ophthalmic examination was conducted for every patient including the following: anterior segment examination with slit-lamp bio microscopy, uncorrected distance visual acuity (UDVA), manifest, cycloplegic refraction, corrected distance visual acuity (CDVA), applanation tonometry, fundus examination, corneal topography by Magellan mapper (Nidek Corporation, Tokyo, Japan) or Pentacam by Allegro Oculyzer (Alcon Wavelight; Alcon, Erlangen, Germany), corneal thickness by ultrasonic pachymetry SP-100 (Nidek Corporation) or by Pentacam, contrast sensitivity testing by test chart 2000 X-pert (Thomson software), and wavefront (WF) analysis using Zernike analysis through nondilated pupil by VISX Wavescan system (Abbot Medical Optics, Santa Clara, California, USA).

Ethical considerations

The risks and advantages of the procedure were explained, and an informed consent was obtained from all patients to whom all the details of the procedure were explained, with emphasis on the intended outcome and possible complications.

Surgical technique

The WFO ablation profile of the Wavelight Allegretto Wave Eye-Q platform (Alcon Wavelight; Alcon) is an aspheric ablation profile. It is a manifest refraction-based treatment that uses a fixed diameter (0.95 mm) flying spot laser with a repetition rate of 400 Hz. The default optical zone for such treatments is 6.5 mm (it can be manipulated from 5 to 7 mm in 0.5 mm steps) with a maximum total treatment zone of 9 mm. The manifest refraction is adjusted according to wavelight nomogram, and it is entered directly into WFO software (Alcon Wavelight; Alcon) of allegretto machine.

The WFG ablation of VISX STAR S4/IR platform (Abbot Medical Optics) changes the beam diameter in a range from 0.65 up to 6.5 mm according to the preoperative WF treatment profile of the patient. It also changes the beam shape and the repetition rate accordingly to meet the precise ablation profile which is needed in the WFG treatments. In addition, the laser machine has also an active 3D eye tracker to ensure the accuracy of the ablation profile. To compensate for cyclotorsion that may happen when the patient lies flat under the laser machine, automated iris registration was activated for all customized eyes before treatment. The refractive data were transmitted to VISX machine by flash memory from WF aberrometer.

For both groups, the optical zone was fixed at 6.5 mm. The surgical technique included the creation of a corneal flap by the Moria M2 mechanical microkeratome (Moria, Antony, France) with the 130 µm single-use head. The choice of the

microkeratome ring was based on recommendations of the nomogram provided by the manufacturer. Laser ablation for both groups was centered on the line of sight (center of the entrance pupil), and centration was controlled by the pupil tracking system in both platform.

Postoperative evaluation

The same postoperative treatment regimen of combined steroid antibiotic eye drops together with nonpreserved artificial tears was followed for all patient. Follow-up was done at 1, 3, and 6 months postoperatively for both groups, where UDVA, CDVA, manifest refraction, contrast sensitivity, and WF error (HOA, coma, trefoil, and spherical aberration) were measured.

Statistical analysis section in the methodology

Data analysis was performed using the software SPSS for Windows, version 20.0 (SPSS Inc., Chicago, Illinois, USA). Normality of data samples was evaluated by means of the Kolmogorov–Smirnov test. When parametric analysis was possible, paired *t*-test was used for comparisons between the preoperative and postoperative data, whereas the Wilcoxon rank sum test (for comparisons between the preoperative and postoperative data) and Mann–Whitney *U*-test (for comparison between postoperative data of both groups) were applied to assess the significance of such differences when parametric analysis was not possible. Bivariate regression analysis was carried out to predict achieved spherical equivalent refraction (SEQ) accuracy using the attempted SEQ data. Correlation coefficients (Pearson's or Spearman's depending if normality condition could be assumed) were used to assess the correlation between different variables. Differences were considered to be statistically significant when the associated *P* value was less than 0.05. Standard graphs for reporting the outcomes in refractive surgery, according to the Waring Protocol and its modifications [8–10], were used for displaying and summarizing the refractive outcomes of this study for each group postoperatively.

Results

Demographic characteristics

The mean age was 27.4±4.29 years ranging from 21 to 33 years in WFO group and 24.82±4.88 years ranging from 18 to 37 years in WFG group. Regarding the sex distribution, four (36.36%) were females and seven (63.64%) were male in WFO group and 12 (70.59%) were females and five (29.41%) were malesin WFG group.

The mean of the corneal thickness was 560.40± 29.22 µm in WFO group and 549.62±42.62 µm in WFG group. The mean of the average *K*s was 43.76± 1.71 D in WFO group and 43.80±1.40 D in WFG. The mean of the spherical error was −2.94±1.40 D in WFO group and −2.78±1.43 D in WFG group. The mean of the cylindrical error was −0.83±0.89 D in WFO group and −1.51±1.43 D in WFG group. The mean of the spherical equivalent was −3.34±1.63 D in WFO and −3.53±1.50 D in WFG group.

Result of refractive evaluation of the two procedures

The WFO group had a mean preoperative CDVA of 0.94±0.16. Six months postoperatively, the mean of UDVA was 0.93±0.15 with efficacy index of 1.02. Preoperatively, 70% of eyes had a CDVA of 1.0, and this percentage decreased to 40% of eyes having an UDVA 1.0 or more, 6 months postoperatively. In the WFG group, the mean preoperative CDVA was 0.87±0.18. Six months postoperatively, the mean of UDVA was 0.96±0.16, with efficacy index of 1.13. Preoperatively, 44.18 of eyes had a CDVA of 1.0, and this percentage increased to 73.96% of eyes having an UDVA 1.0 or more 6 months postoperatively as shown in Fig. 1a and b. A statistically significant difference existed between both groups in efficacy index (P=0.012).

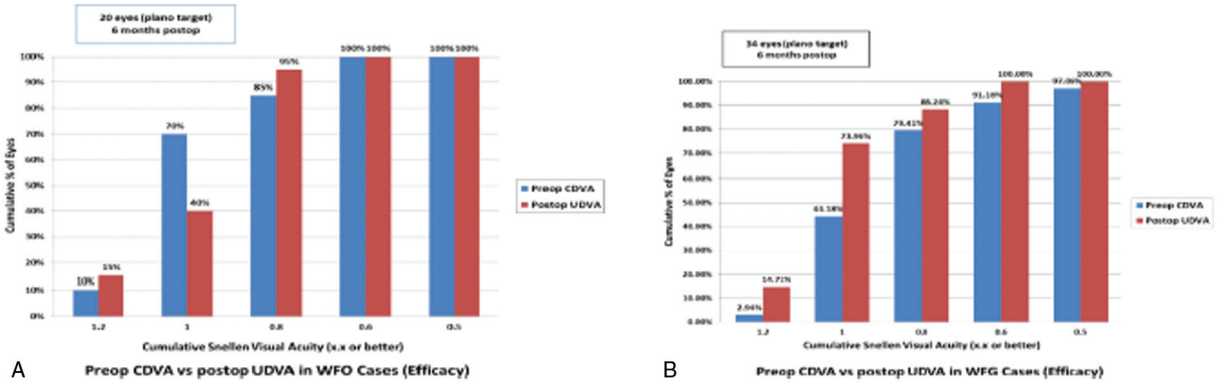
The safety index was 1.11 in WFO group and 1.17 in WFO group, with no statistically significant difference between both groups in safety index (P=0.22). In the WFO group, 35% of eyes gained two lines or more, and none of the eyes lost any lines from preoperative CDVA, whereas in the WFG group, 35.29% of eyes gained two lines or more and 2.94% lost two or more lines from preoperative CDVA, as shown in Fig. 2a and b.

The WFO group showed high predictability, where 90% eyes were within ±0.5 D of emmetropia at 6 months postoperatively, whereas in the WFG group, 68% eyes were within ±0.5 D of emmetropia at 6 months postoperatively, as shown in Fig. 3a and b.

Regarding accuracy in correction of refractive astigmatism, 100% of eyes in WFO group and 67.65% of eyes in WFG group were within ±0.5 D of emmetropia at 6 months postoperatively as shown in Fig. 4a and b.

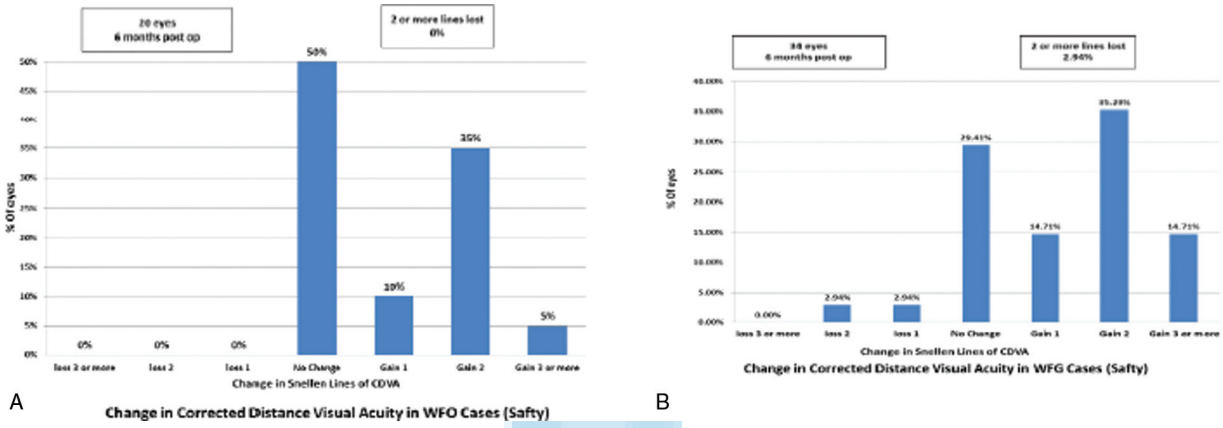
The two techniques showed good stability of refraction during the 6 months postoperative follow-up period,

Figure 1



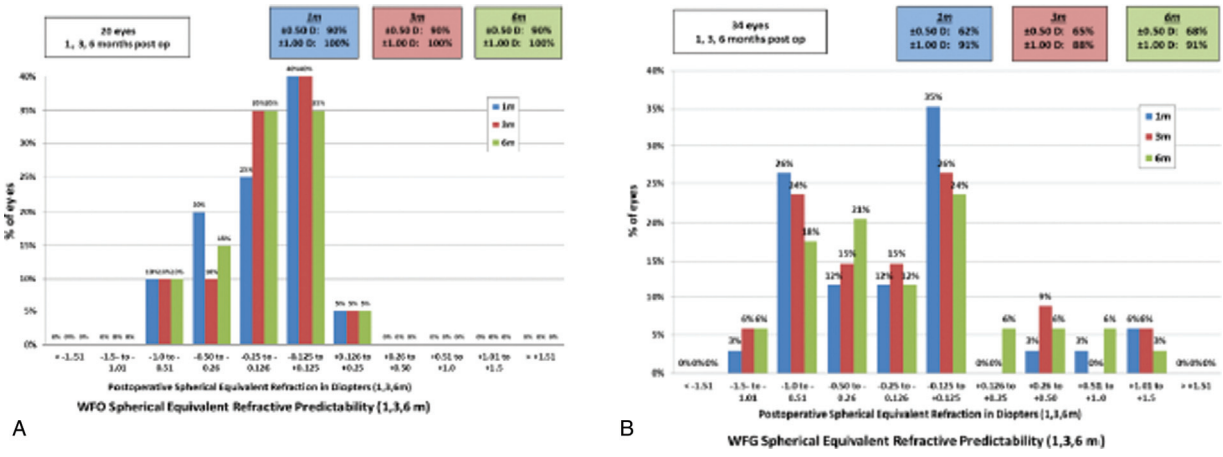
Pre and postoperative CDVA in both study groups. Comparison between both groups as regard postoperative UDVA vs Preoperative CDVA. CDVA, corrected distance visual acuity.

Figure 2



(Right, left) Postoperative changes in preoperative CDVA in both groups. CDVA, corrected distance visual acuity; WFG, wavefront-guided; WFO, wavefront-optimized.

Figure 3

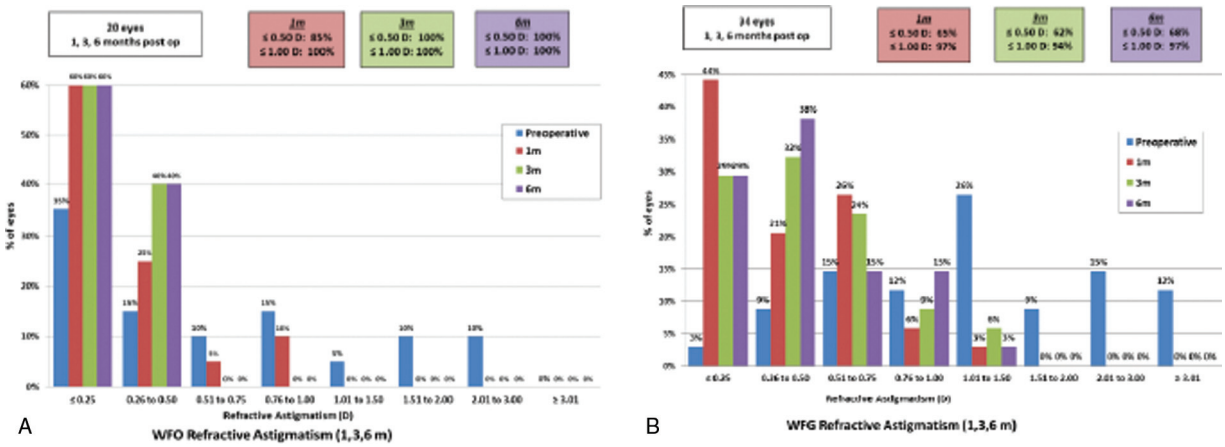


(a, b) postoperative SEQ refraction (1, 3, 6 months) in both groups. WFG, wavefront-guided; WFO, wavefront-optimized.

where none of the eyes in WFO group and 14.70% of the eyes in WFG group showed changed more than 0.50 D, as shown in Fig. 5a and b.

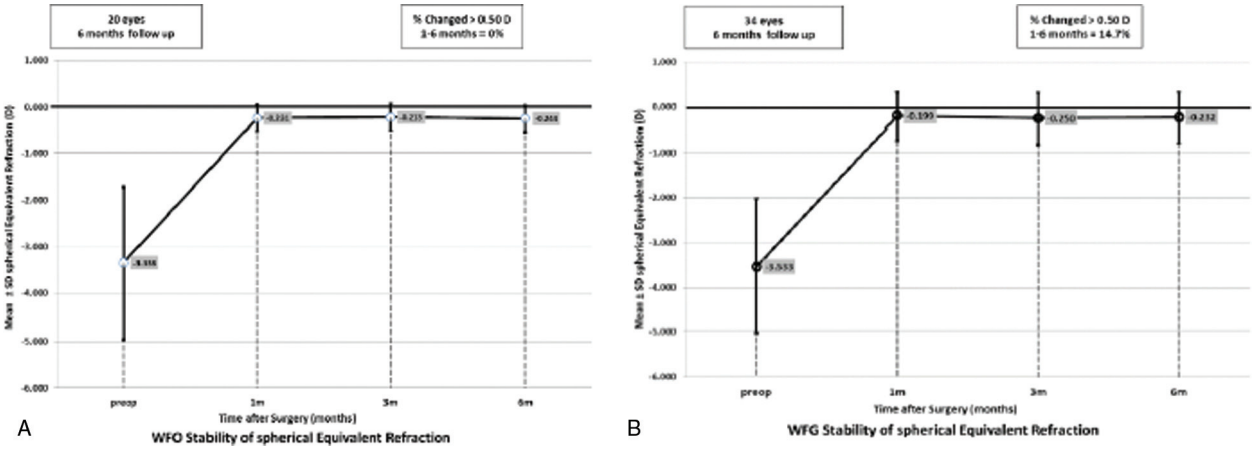
Regarding accuracy, Fig. 6a and b shows the attempted versus the achieved manifest rarefaction spherical equivalent (MRSE), with strongly positive correlation

Figure 4



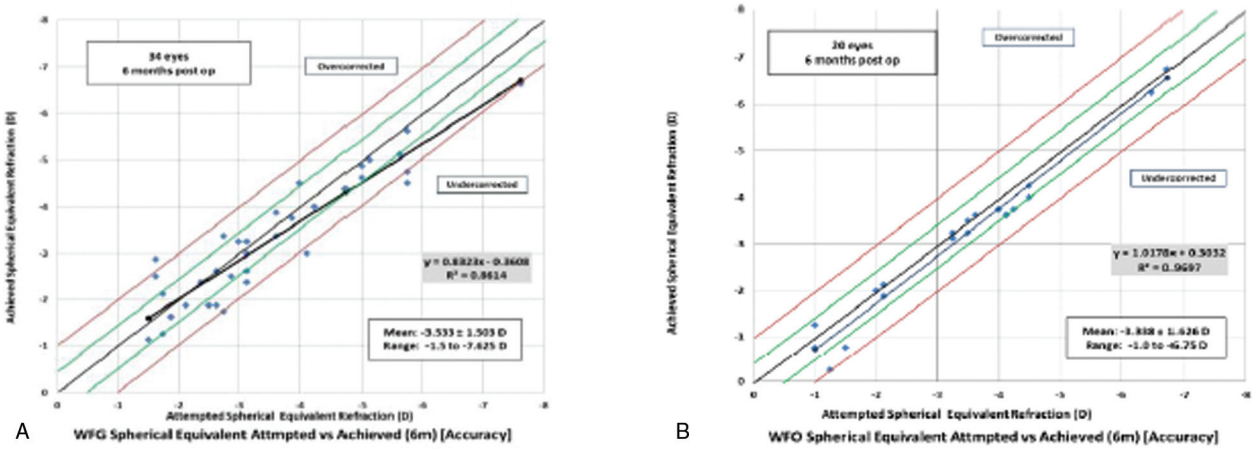
(a, b) Postoperative refractive astigmatism of both groups (1, 3, 6 months). WFG, wavefront-guided; WFO, wavefront-optimized.

Figure 5



(a, b) Postoperative refractive stability in both groups (1, 3, 6 months).

Figure 6



(a, b) Attempted spherical equivalent versus achieved 6 months postoperatively in both groups. WFG, wavefront-guided; WFO, wavefront-optimized.

(r=0.979) for the WFO group and (r=0.928) for WFG group.

Higher order aberrations

Six months postoperatively, a statistically significant induction of HOA RMS was observed, with a mean of 0.25±0.21 µm (P=0.001) in WFO group and a mean of 0.09±0.11 µm (P=0.000) in WFG group. A statistically significant difference existed between WFG and WFO for induced HOA RMS (P=0.002).

Regarding spherical aberration, 6 months postoperatively, a statistically significant change was observed in absolute value of spherical aberration, with a mean of 0.08±0.21 µm (P=0.05) in WFO group and 0.16±0.16 µm (P=0.000) in WFG group. A statistically significant difference existed between WFG and WFO in induced spherical aberration (P=0.018).

Both groups showed a nonsignificant induction of spherical aberration RMS 6 months postoperatively, with a mean of 0.3±0.12 and 0.09±0.17 µm in WFO and WFG groups, respectively.

Regarding coma RMS, both groups showed a nonsignificant change in mean of coma RMS 6 months postoperatively. The mean of induced coma RMS was 0.17±0.23 and 0.01±0.30 µm in WFO and WFG groups, respectively (P=0.835).

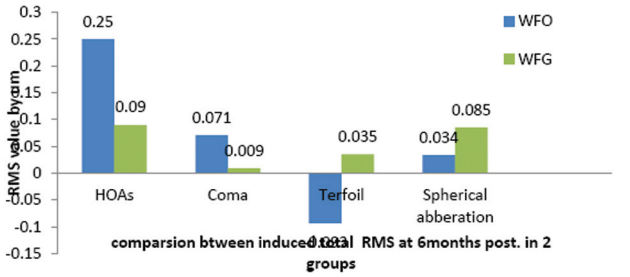
In WFO group, a statistically significant decrease was observed in trefoil RMS, with a mean −0.09±0.23 µm at 6 months postoperatively (P=0.023). On the other hand, in the WFG group, a nonsignificant increase was observed in trefoil RMS, with a mean 0.04±0.15 µm at 6 months postoperatively (P=0.478).

This resulted in a statistically significant difference between WFO and WFG at 6 months postoperatively in induced trefoil (P=0.005) as shown in Fig. 7 and Table 1.

Contrast sensitivity

Contrast sensitivity was tested at the frequency of 3 cycles per degree. In WFO group, there was a statistically significant improvement in the mean of contrast sensitivity value from 1.54±0.31 preoperatively to 1.86±0.10 at 6 months postoperatively (P=0.000). In WFG group, there was a statistically significant improvement in mean contrast sensitivity value from 1.68±0.12 preoperatively to 1.85±0.17 at 6 months postoperatively (P=0.000). Regarding preoperative intergroup comparison in contrast sensitivity value,

Figure 7



Total induced RMS in the two groups at 6 months postoperatively. RMS, root mean square; WFG, wavefront-guided; WFO, wavefront-optimized.

there was a statistically significant difference between both groups (P=0.000), so each group was compared separately as shown in Fig. 8.

Discussion

When HOAs cannot be corrected, image quality may suffer. The HOAs call for more advanced optical measurements and more sophisticated laser algorithms [11]. These laser algorithms are found in WF-based treatments, which have been shown to diminish induced HOAs compared with traditional LASIK and increase predictability of visual outcomes [12,13]. As WF-based methods have evolved rapidly over the years. Our aim was evaluation and comparison of the visual and refractive outcomes of WFO and WFG LASIK regarding predictability, safety, and efficacy, HOA, and contrast sensitivity.

Regards efficacy, preoperatively, the WFO group had CDVA of 1.0 in 70% of eyes. Six months postoperatively, 40% of eyes have an UDVA of 1.0 or more. This postoperative result was less than that reported by Perez-Straziota *et al.* [14], Stonecipher and Kezirian [15], Padmanabhan *et al.* [16], Miraftab *et al.* [17], Moshirfar *et al.* [12], and Yu *et al.* [18], who found that postoperative UDVA of 20/20 or more was in 86, 93, 82, 83.8, 91%, and 95% of eyes, respectively. The decrease in postoperative UDVA in WFO group was attributed to presence of two amblyopic eyes, and four eyes had residual refractive error.

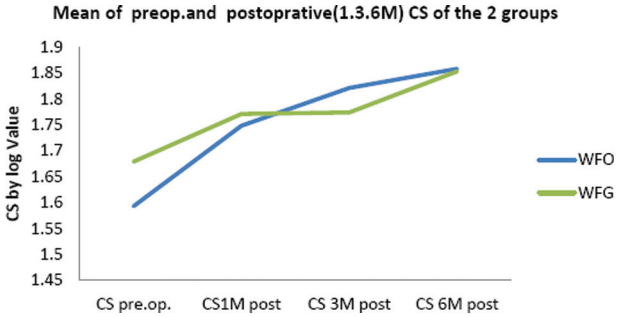
Preoperatively, the WFG group had CDVA of 1.0 in 44.18% of eyes. Six months postoperatively, 73.96% of eyes having an UDVA of 1.0 or more. These results were less than that obtained by Miraftab *et al.* [17], Perez-Straziota *et al.* [14], Yu *et al.* [18], Stonecipher and Kezirian [15], Padmanabhan *et al.* [16], and Moshirfar *et al.* [12], who found that UDVA was 1.0 in 89, 85, 86, 93, 92, and 91% of eyes, respectively.

Table 1 A comparison of induced higher order aberration of the two groups 6 months postoperatively

Induced aberration	Wavefront-optimized root mean square value (μm)	Wavefront-guided root mean square value (μm)	*P* value
Higher order aberration	0.25±0.21	0.09±0.11	0.002*
Trefoil	–0.09±0.23	0.04±0.15	0.005*
Spherical aberration	0.03±0.12	0.09±0.17	0.467
Coma	0.07±0.23	0.01±0.30	0.835

Significance was determined at $P \leq 0.05$. *Statistically significant differences.

Figure 8



A comparison between CS test in both groups preoperatively and 6 months postoperatively.

The efficacy index was 1.02 in WFO group and 1.13 in WFG group, with a statistically significant difference between WFG and WFO groups (P=0.012).

Other studies conducted by Miraftab *et al.* [17], Perez-Straziota *et al.* [14], Yu *et al.* [18], Stonecipher and Kezirian [15], Padmanabhan *et al.* [16], and Moshirfar *et al.* [12] showed no significant difference between WFO and WFG groups in efficacy.

Regarding safety, in WFO group, the percentage of eyes which gained or lost lines from preoperative CDVA were less than that obtained by Padmanabhan *et al.* [16], who found that 11% of eyes lost one line and 15% gained one line, and Moshirfar *et al.* [12], who reported that 41% of eyes showed no change in postoperative CDVA than preoperative CDVA and only 5% of eyes lost one line.

The safety index in WFO group was 1.11, which was less than the safety index 1.26 reported by Stojanovic *et al.* [19] and more than 1.06 that reported by Khalifa *et al.* [20].

In WFG group, the percentage of eyes who gain or lost lines from CDVA were more than that obtained by Padmanabhan *et al.* [16], who found that 11% of eyes lost one line and 15% gained one line. Moshirfar *et al.* [12] reported that 55% of eyes showed no change in postoperative CDVA than preoperative CDVA whereas only 41% lost two lines. In WFG group, safety index was 1.18, which higher than 1.12 that was obtained by Nuijts *et al.* [21].

WFG group had results superior to WFO group for safety, with no significant difference existed between WFG and WFO groups regarding safety index (P=0.22).

Both WFO and WFG were accurate in correction of MSRE. A statistically significant difference between attempted versus achieved postoperative MSRE (P=0.000) was observed in each group.

In WFO group, 90% of the eyes were within ±0.5 D of emmetropia. The results of current study were similar to that obtained by Padmanabhan *et al.* [16], who found that 89% of eyes (27 eye) were within ±0.50 D of emmetropia at 1 month postoperatively. However, this result was different from that was obtained by Perez-Straziota *et al.* [14], who reported in their study that 96% of eyes (66 eyes) of WFO were within ±0.50 D of emmetropia at 3 months postoperatively; Yu *et al.* [18], who found that 95% of the eyes (108 eyes) were ±0.50 D of the target refraction at 3 months postoperatively; Stojanovic *et al.* [19], who reported that 91% of eyes (42 eyes) were ±0.5 D of emmetropia at 3 months postoperatively; and Stonecipher and Kezirian [15], who showed that MRSE was within ±0.50 D in 94% of eyes (186 eyes) at 3 months postoperatively. This difference may be related to large sample size in these studies.

In WFG group, 68% of the eyes were within ±0.5 D of emmetropia. This result was lower than that reported by Perez-Straziota *et al.* [14], Yu *et al.* [18], Stonecipher and Kezirian [15], and Padmanabhan *et al.* [16], who found that more than 90% of eyes were within ±0.5 D of emmetropia postoperatively.

WFO group was superior to WFG group regarding refractive predictability, correction refractive astigmatism, and refractive stability. This was attributed

to WFG techniques having some limiting factors including pupil size requirements, mismatch to manifest refraction which was mostly due to over accommodation, and the timely process of uploading WF data. In contrast, Allegretto Wavelight Eye-Q laser functions at a higher frequency, therefore allowing faster operating times. Additionally, the Allegretto platform does not require iris registration, which can sometimes be difficult to obtain intraoperatively, and there is no issue with mismatch to manifest refraction.

Higher order aberrations root mean square and induced higher order aberrations root mean square

Both groups showed a statistically significantly increase in HOA RMS value at 6 months postoperatively compared with preoperative HOA RMS value, with *P*=0.000 in WFO group and *P*=0.000 in WFG group. In WFO group, a statistically significant induction of HOA RMS with a mean of 0.25±0.21 μm was found (*P*=0.003). This increase in HOA was near to that reported by Miraftab *et al.* [17] and Khalifa *et al.* [14]; who found that it increased with a mean of 0.19 ±0.08 μm and 0.18±0.22 μm, respectively, at 3 months postoperatively. However, Moshirfar *et al.* [12] reported an increase in HOA RMS of 4% (0.012), as they created LASIK flap by femtosecond laser which theoretically induces less HOA.

In WFG group, a statistically significant induction of HOA RMS with a mean of 0.09±0.11 μm was found (*P*=0.003). The increase in HOA was less than that reported by Miraftab *et al.* [17] and Koller *et al.* [22], who found that HOA increased with a mean of 0.17 ±0.09 and 0.14±0.07 μm, respectively, postoperatively, but similar to Moshirfar *et al.* [12], who reported an increase in HOA RMS [9% (*P*=0.125)].

Regarding intergroup comparison, WFO group showed high value of induced HOA RMS than WFG. A statistically significant difference existed between WFG and WFO groups (*P*=0.002). This was attributed to the fact that WFO ablation prevents but does not treat pre-exciting HOA and WFG prevents and treats HOA. These results are similar to that reported by Padmanabhan *et al.* [16], who reported a trend toward a slightly better performance of WFG versus WFO; Perez-Straziota *et al.* [14], who reported that no significant differences in HOA between WFG and WFO groups; and Feng *et al.* [23], who reported no difference between WFO and WFG in induction of HOA for patients with preoperative HOA RMS less than 0.30 μm. However, in eyes with preoperative HOA RMS more than 0.30 μm, the WFG profile induced less postoperative HOAs than the WFO profile.

Coma root mean square and induced coma root mean square

Six months postoperatively, coma RMS increased nonsignificantly in both groups. WFG group had less value in induced coma than WFO group. In WFO group, the mean of induced coma was 0.07 ±0.23 μm. This result goes with Moshirfar *et al.* [12], who reported that coma increased 11% nonsignificantly. In WFG group, the mean of induced coma was 0.01±0.0.3 μm. This result was less than 0.16±0.08 μm that reported by Stojanovic *et al.* [19]. However, Moshirfar *et al.* [12] found that coma decreased 18% nonsignificantly.

Trefoil root mean square and induced trefoil root mean square

In WFO group, a statistically significant decrease in the mean of trefoil RMS was found (*P*=0.023). However, in the WFG group, a nonsignificant increase in the mean of trefoil RMS was detected (*P*=0.478) at 6 months postoperatively. In WFO group, the mean of induced trefoil RMS was −0.09 ±0.23 μm. This result was better than that reported by Moshirfar *et al.* [12], who found trefoil decreased by 5% (*P*=0.239). On other hand Stojanovic *et al.* [19] and Khalifa *et al.* [20], who found that trefoil RMS increase with a mean of 0.03±0.01 and 0.002 ±0.12 μm, respectively, after surgery. In WFG group, the mean of induced trefoil RMS was 0.04 ±0.15 μm. This result is less than that reported by Moshirfar *et al.* [12], who found that trefoil decrease by 19% (*P*=0.660). A statistically significant difference was found between both groups in induced trefoil at 6 months postoperatively (*P*=0.005).

Spherical aberration and spherical aberration root mean square

Both groups showed significant increase in positive spherical aberration at 6 months postoperatively. Induction of spherical aberration was significant in WFG group and nonsignificant in WFO group, with a statistically significance difference found between both groups (*P*=0.018).

On the contrary, spherical aberration RMS increased significantly in WFG group and nonsignificantly in WFO group, with no significant induction of spherical aberration RMS in both groups at 6 months postoperatively. These results go with that reported by Koller *et al.* [22] who found nonsignificant increase in spherical aberration RMS in WFG group. Moshirfar *et al.* [12] reported in their study that spherical aberration RMS increased nonsignificantly

in WFO group and decreased nonsignificantly in WFG group.

WFO group had high value of induced spherical aberration RMS than WFG group. This may be referred to ablation profile in WFO which prevents induced spherical aberration and because WFG group had large number of eyes.

Spherical aberration shows the largest increase after excimer laser refractive surgery [24]. This increase in spherical aberration is highly correlated with preoperative refraction. Therefore, the change of corneal asphericity induced by myopic ablations is an important factor influencing the increase of spherical aberration after laser refractive surgery [25]. Dupps and Roberts [26] demonstrated that the peripheral corneal lamellae retract and thicken after surface-based phototherapeutic keratectomy. Marshall *et al.* [27] showed ultra-structural proof of peripheral corneal change outside an ablation zone. Such anatomical changes will lead to an increase in spherical aberration. Potgieter *et al.* [28] believes that the mechanism proposed by Dupps and Roberts [26] comes into action when the mid peripheral corneal lamellae are detached mechanically during lamellar flap cutting, and that these changes stabilize over time until equilibrium is reached at the 6-week to 3-month time period.

Contrast sensitivity

Contrast sensitivity was tested using 3c/d test, which was used in this study. In this software, each letter is equivalent to 3c/d (which is equivalent to visual frequency of 20/200 on Snellen visual acuity chart). This is considerd a low spatial frequency.

Both groups showed a statistically significant improvement in the mean of contrast sensitivity value at 6 months postoperatively compared with preoperative value, with P=0.001 in WFO group and P=0.000 in WFG group. WFG group was high in improvement of contrast sensitivity (CS) value than WFO. This result differ from that found by Padmanabhan *et al.* [16] and Moshirfar *et al.* [12], who reported that CS value changed nonsignificantly postoperatively in both WFO and WFG groups at low spatial frequencies. Moreover, Khalifa *et al.* [20], reported nonsignificant improvement postoperatively in CS at all spatial frequencies in WFO group.

Howland [29], concluded that high contrast acuity decreases at a slower rate than low contrast acuity as corneal aberrations increase. Another study was conducted by Applegate *et al.* [30] that correlated the change in total eye aberrations induced by refractive surgery to measure the visual performance. Using the tscherning aberroscope, they measured 15 eyes before and 3 months after myopic photorefractive keratectomy [30]. The visual performance was measured using high contrast acuity, low contrast acuity, and glare visual acuity. The increase in the total WF error correlated most with loss in low contrast acuity, followed by a glare visual acuity and then a high contrast acuity. Verdon *et al.* [31] reported a strong correlation between the correction of HOAs and the best-corrected visual acuity, low contrast visual acuity, and glare visual acuity.

The drawbacks of this study include the use of different surgeons for each group and the short-term follow-up. Moreover, the sample size in the current study was smaller than other studies. In addition, most of the studies compare WFO LASIK in one eye versus WFG LASIK in other eye, so it is better to be designed in an intrapatient method (i.e. contralateral study) as was done by Padmanabhan *et al.* [16], Koller *et al.* [22], and Stonecipher and Kezirian [15]. Moreover, most of the studies compare WFG and WFO on the same platform of laser machine (Allegretto Wavelight).

Currently, there is consensus that in cases with considerable preoperative HOAs RMS or those undergoing retreatment, the WFG approach is preferred. Finally, we can conclude that both WFG and WFO approaches are safe, effective, and predictable options in the treatment of previously unoperated eyes, and results obtained with WFG LASIK are as accurate as WFO LASIK in most patients, unless there is significant preoperative HOAs.

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Conflicts of interest

There are no conflicts of interest.

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