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Treatment of mixed astigmatism: early clinical outcomes with WaveLight and Technolas excimer lasers

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Background/aim: We aimed to compare the results of WaveLight Allegretto Wave Eye-Q 400 Hz and Technolas 217z100 excimer lasers in the treatment of mixed astigmatism.

Materials and methods: Forty-nine patients who underwent laser in situ keratomileusis for mixed astigmatism were included in this retrospective study. Twenty-eight eyes of 21 patients were treated with WaveLight and 46 eyes of 28 patients were treated with the Technolas excimer laser. The patients' visual acuities and refractive values were evaluated on postoperative day 1 and at 1 and 3 months.

Results: In the WaveLight and Technolas groups, cylindrical refractive errors at month 3 were –0.92 ± 0.28 D and –0.88 ± 0.46 D, respectively. Spherical equivalent values for the groups at month 3 were –0.38 ± 0.73 D and –0.33 ± 0.20 D, respectively. There was no significant difference in postoperative uncorrected distance visual acuity at month 3 between the two groups (P = 0.671). At postoperative month 3, 70% of patients treated with WaveLight and 100% of patients treated with Technolas had an uncorrected distance visual acuity of 20/25 or better (P = 0.211).

Conclusion: There were no significant differences in refraction and visual acuity between the WaveLight and Technolas groups during a 3-month follow-up period after laser in situ keratomileusis for mixed astigmatism.

Key words: Excimer laser, laser in situ keratomileusis, mixed astigmatism

1. Introduction

Today many excimer laser systems have software programs for treating mixed astigmatism. Different approaches have been reported: negative-cylinder nomogram, positive-cylinder nomogram, cross-cylinder technique, bitoric ablation, and sequential ablation. The common goal in the treatment of mixed astigmatism is to remove the minimum amount of tissue while achieving good visual results (1,2).

In mixed astigmatism, one focal line is projected in front of the retina while the other focal line is projected behind the retina. Therefore, the ablation profile of mixed astigmatism is more complex (3). Myopia correction in one meridian and hyperopia correction in the other meridian are the goals (4). Thus, the results are less predictable than those in the correction of simple or compound astigmatism. Residual or induced astigmatism is usually a frequent cause of patient dissatisfaction after laser in situ keratomileusis (LASIK) for mixed astigmatism.

To correct mixed astigmatism, the WaveLight Allegretto Wave Eye-Q 400 Hz excimer laser (WaveLight GmbH, Alcon, USA) uses the bitoric ablation profile. According to the Food and Drug Administration (FDA) approved indications for excimer lasers for LASIK management of mixed astigmatism, up to 6.00 D of mixed astigmatism on the spectacle plane is approved for WaveLight Allegretto Wave excimer laser treatment (4). The Technolas 217z100 excimer laser (Bausch & Lomb, USA) uses sequential ablation (Bausch & Lomb), in which the positive cylinder is treated first and the negative sphere is treated later. Therefore, the device uses two different nomograms during the same surgical operation. The Technolas 217z100 excimer laser does not have FDA approval for LASIK management of mixed astigmatism. In the present paper the early clinical outcomes and the safety and efficacy of these two laser systems are compared. To the best of our knowledge, this paper is the first to compare

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two different ablation algorithms in LASIK treatment of mixed astigmatism.

2. Materials and methods

The Institutional Review Board of Acıbadem University granted approval for the present study. The medical records of patients who underwent LASIK surgery using either the WaveLight Allegretto Wave Eye-Q 400 Hz or Technolas 217z100 excimer laser at the Acıbadem Maslak Hospital Eye Clinic from 1 January 2010 to 31 May 2014 were evaluated retrospectively. All patients met the following criteria: age >21 years, preoperative mixed and regular astigmatism, and absence of corneal diseases. Exclusion criteria included: a predicted residual stromal bed thickness of <250 μm, suspicion of keratoconus, irregular astigmatism, and previous ocular surgery. Written informed consent related to the surgical procedures was obtained from all patients prior to surgery.

All patients had a complete preoperative ophthalmological examination, including uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), manifest and cycloplegic refraction, intraocular pressure (IOP) with air-puff tonometry (CT-80, Topcon, Japan), corneal pachymetry and topography (Pentacam, Oculus, Germany), scotopic pupil measurement (Colvard pupillometer, Oasis, USA), and fundoscopy.

Surgeries were performed by two surgeons (CBCY and ABŞ) at the Acıbadem Maslak Hospital Eye Clinic. After topical anesthesia with 0.5% proparacaine hydrochloride (Alcaine, Alcon Laboratories, USA), a sterile drape and an eyelid speculum were positioned. A Hansatome XP microkeratome (Bausch & Lomb) was used to create a 120-μm-thick corneal flap. The suction ring was selected depending on the corneal diameter (8.5 mm or 9.5 mm). After the flap was created, it was raised with a spatula. The stromal bed was dried with a sponge and the ablation was performed using either the WaveLight Allegretto Wave Eye-Q 400 Hz or Technolas 217z100 excimer laser. After the ablation, the stroma was washed with balanced salt solution and the flap was repositioned with the help of a cannula. One drop of 0.5% moxifloxacin hydrochloride ophthalmic solution (Vigamox, Alcon Laboratories) was applied at the end of the procedure. Postoperatively Vigamox was prescribed 3 times daily for 5 days and 0.5% loteprednol etabonate ophthalmic suspension (Lotemax, Bausch & Lomb) was prescribed starting with 5 times daily and tapering over 5 days. Preservative-free artificial tears were used as needed. Patients were examined on postoperative day 1 and at 1 and 3 months. UDVA, CDVA, IOP, and objective and subjective refraction were measured. Safety was calculated by the following equation: postoperative CDVA/preoperative CDVA. Efficacy was calculated by the following equation: postoperative UDVA/preoperative CDVA.

SPSS 17.0 was used for the statistical analysis. Visual acuity was converted to the logarithm of the minimum angle of resolution from the decimal notation for statistical analysis. Descriptive data were expressed as mean ± SD. The chi-square and Fisher exact tests were used to determine differences in categorical data. Data normality was confirmed by the Kolmogorov–Smirnov test. The WaveLight and Technolas groups were compared by the Mann–Whitney U test. One-way ANOVA for repeated measures was used to evaluate the changes in spherical, cylindrical, and spherical equivalent values postoperatively. $P < 0.05$ was considered significant.

3. Results

Twenty-eight eyes of 21 patients (13 females and 8 males) who were treated with the WaveLight Allegretto Wave Eye-Q 400 Hz excimer laser (WaveLight group) and 46 eyes of 28 patients (13 females and 15 males) who were treated with the Technolas 217z100 excimer laser (Technolas group) were included in the present study. The patients in the WaveLight group met the FDA approved criteria for LASIK management of mixed astigmatism. The mean age was 35.62 ± 12.60 (21–66) years in the WaveLight group and 34.29 ± 8.70 (21–66) years in the Technolas group ($P = 0.992$). Demographic data and preoperative mean IOP, UDVA, CDVA, spherical error, cylindrical error, spherical equivalent, and central corneal thickness values are shown in Table 1. There was no significant difference in demographic data and preoperative values between the two groups as shown in Table 1.

Mean UDVA, CDVA, sphere, cylinder, and spherical equivalent values at postoperative day 1, month 1, and month 3 in the WaveLight and Technolas groups are shown in Table 2. The mean spherical and spherical equivalent values were significantly lower in the Technolas group than in the WaveLight group on postoperative day 1 ($P = 0.043$ and $P = 0.017$, respectively), but there was no significant difference in visual and refractive results at postoperative month 1 and month 3 between the two groups ($P > 0.05$), as shown in Table 2 (Figures 1–3).

Patients with preoperative cylinder values of ≥5.00 D were excluded and further analyses were performed with the remaining population (Table 3). There were no significant differences regarding the mean cylindrical refraction between the WaveLight group and the Technolas group at postoperative month 1 and month 3 ($P = 0.568$ and $P = 0.470$, respectively).

The patients who had postoperative day 1, month 1, and month 3 measurements were also analyzed for repeated measurements of spherical, cylindrical, and spherical equivalent values (Table 4). There was a significant change in spherical values between postoperative day 1 and month 3 measurements in the Technolas group ($P = 0.028$). However, there were no significant regressions in spherical, cylindrical, or spherical equivalent values from

Table 1. Demographic data and preoperative values of eyes in the WaveLight and Technolas groups.

Variables	WaveLight (n = 28)	Technolas (n = 46)	P
Age (years)	35.62 ± 12.60 (21–66)	34.29 ± 8.70 (21–66)	0.992
Sex (F/M)	13/8	13/15	0.283
IOP (mmHg)	16.00 ± 3.17 (11–25)	15.84 ± 3.22 (11–23)	0.866
UDVA (decimal)	0.27 ± 0.16 (0.1–0.6)	0.28 ± 0.16 (0.1–0.7)	0.876
CDVA (decimal)	0.84 ± 0.22 (0.2–1.0)	0.83 ± 0.19 (0.2–1.0)	0.303
Sphere (D)	1.58 ± 1.02 (0.25–4.25)	1.67 ± 1.43 (0.25–5.25)	0.626
Cylinder (D)	–3.19 ± 1.19 (–5.25 to –1.25)	–3.62 ± 1.42 (–6.75 to –1.50)	0.274
SE (D)	–0.01 ± 1.04 (–2.38 to –1.88)	–0.14 ± 1.16 (–2.38 to 2.88)	0.349
CCT (μm)	553.96 ± 33.62 (496–622)	556.74 ± 36.37 (481–658)	0.806

F: female; M: male; IOP: intraocular pressure; UDVA: uncorrected distance visual acuity; CDVA: corrected distance visual acuity; D: diopter; SE: spherical equivalent; CCT: central corneal thickness.
P: Mann–Whitney U test, chi-square test.

Table 2. Postoperative day 1, month 1, and month 3 results in the WaveLight and Technolas groups.

Follow-up visits	Variables	WaveLight	Technolas	P
Post-op day 1	n	28	46	
	UDVA (decimal)	0.80 ± 0.21	0.81 ± 0.21	0.825
	CDVA (decimal)	0.88 ± 0.17	0.86 ± 0.19	0.585
	Sphere (D)	–0.23 ± 0.67	0.06 ± 0.45	0.043
	Cylinder (D)	–0.86 ± 0.52	–0.69 ± 0.43	0.157
	SE (D)	–0.66 ± 0.72	–0.28 ± 0.41	0.017
Post-op month 1	n	19	23	
	UDVA (decimal)	0.81 ± 0.21	0.81 ± 0.20	0.845
	CDVA (decimal)	0.91 ± 0.16 (n = 14)	0.84 ± 0.20	0.205
	Sphere (D)	0.19 ± 0.50	0.40 ± 0.60	0.336
	Cylinder (D)	–0.59 ± 0.74	–0.81 ± 0.44	0.409
	SE (D)	–0.09 ± 0.63	–0.00 ± 0.46	0.559
Post-op month 3	n	10	9	
	UDVA (decimal)	0.81 ± 0.19	0.88 ± 0.09	0.671
	CDVA (decimal)	0.92 ± 0.18 (n = 7)	0.93 ± 0.10	0.529
	Sphere (D)	0.07 ± 0.78	0.11 ± 0.37	0.901
	Cylinder (D)	–0.92 ± 0.28	–0.88 ± 0.46	1.000
	SE (D)	–0.38 ± 0.73	–0.33 ± 0.20	0.562

UDVA: uncorrected distance visual acuity; CDVA: corrected distance visual acuity; D: diopter; SE: spherical equivalent;
P: Mann–Whitney U test. Bolded values are significant at $P < 0.05$.

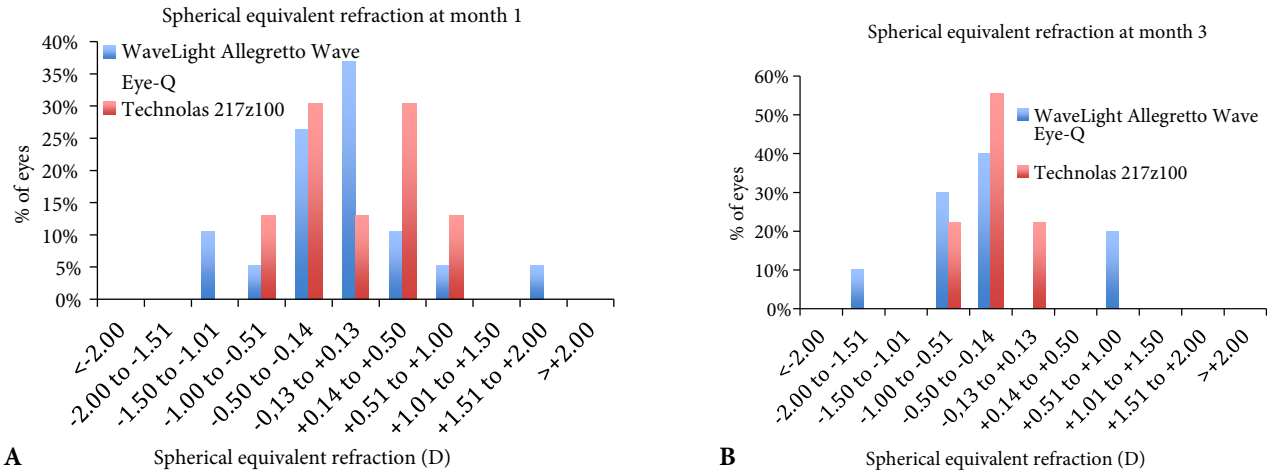

Figure 1. Spherical equivalent refractive accuracy at postoperative month 1 and month 3 in the WaveLight and Technolas groups. A: Month 1; B: Month 3.

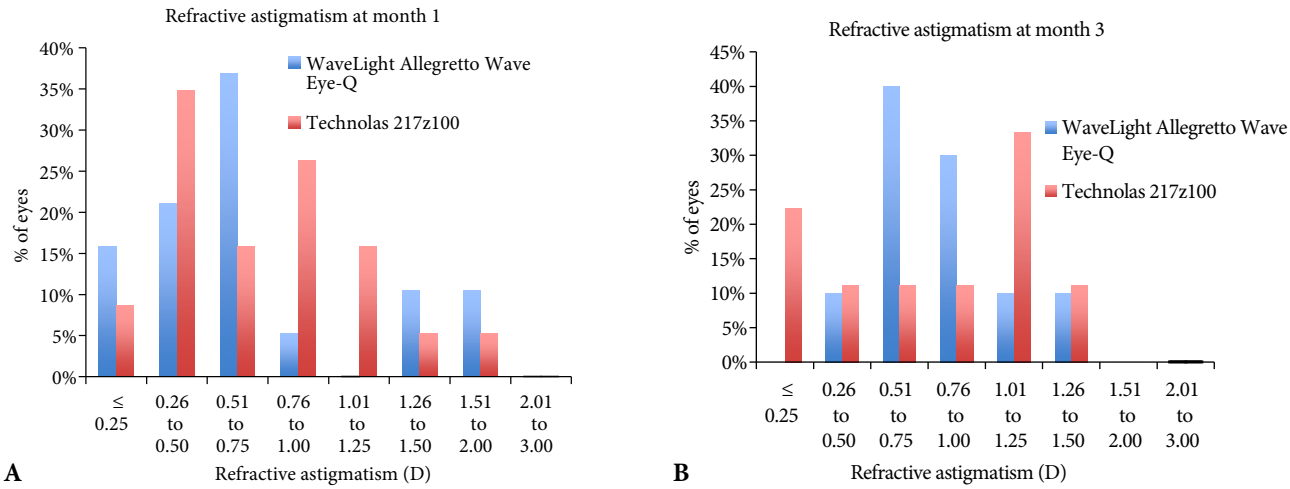

Figure 2. Refractive astigmatism at postoperative month 1 and month 3 in the WaveLight and Technolas groups. A: Month 1; B: Month 3.

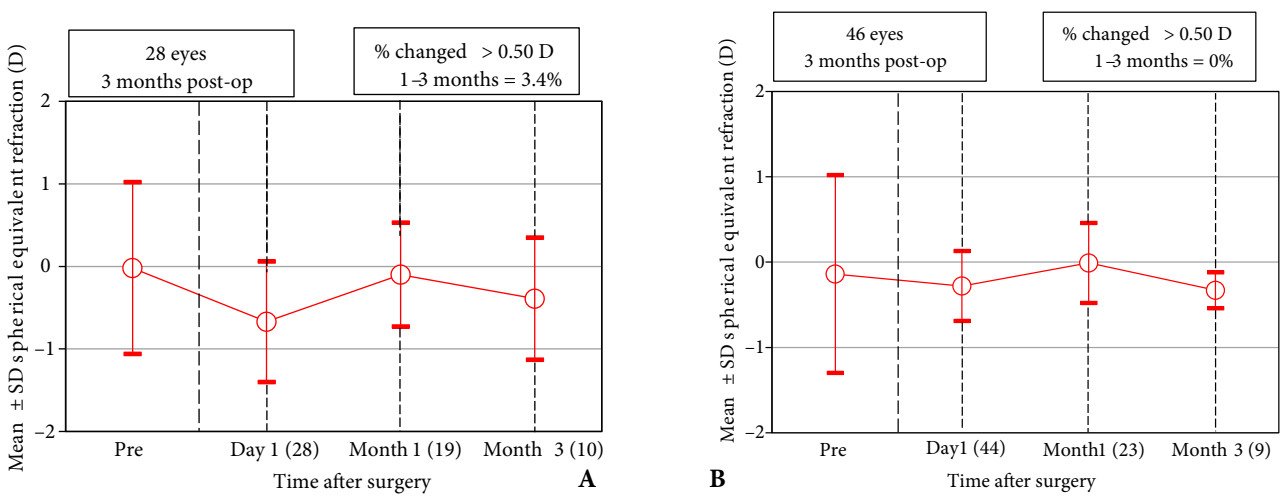

Figure 3. Stability of spherical equivalent refraction after laser in situ keratomileusis in the WaveLight and Technolas groups. A: WaveLight group; B: Technolas group.

Table 3. Comparisons of mean cylinder outcomes in the WaveLight group and the Technolas group after excluding patients with preoperative cylinder refraction of ≥5.00 D.

Cylinder (D)	WaveLight (n)	Technolas (n)	P
Preoperative	−3.04 ± 1.10 (26)	−2.97 ± 0.85 (35)	0.815
Post-op day 1	−0.85 ± 0.52 (26)	−0.56 ± 0.31 (33)	0.049
Post-op month 1	−0.54 ± 0.72 (18)	−0.70 ± 0.34 (17)	0.568
Post-op month 3	−0.88 ± 0.28 (9)	−0.96 ± 0.50 (7)	0.470

D: diopter.
P: Mann–Whitney U test. Bolded values are significant at $P < 0.05$.

Table 4. Postoperative changes in spherical, cylindrical, and spherical equivalent values in the WaveLight and Technolas groups.

	Variables	Post-op day 1	Post-op month 1	Post-op month 3	P
WaveLight	n	8	8	8	
	Sphere (D)	0.00 ± 0.84	0.34 ± 0.61	0.18 ± 0.84	0.076
	Cylinder (D)	−1.00 ± 0.48	−0.90 ± 0.37	−0.96 ± 0.28	0.420
	SE (D)	−0.54 ± 0.97	−0.10 ± 0.58	−0.29 ± 0.80	0.057
Technolas	n	9	9	9	
	Sphere (D)	−0.11 ± 0.41	−0.05 ± 0.30	0.11 ± 0.37	0.036
	Cylinder (D)	−0.69 ± 0.30	−0.66 ± 0.43	−0.88 ± 0.46	0.150
	SE (D)	−0.45 ± 0.38	−0.38 ± 0.18	−0.33 ± 0.20	0.527

D: diopter; SE: spherical equivalent.
P: One-way ANOVA for repeated measures, bolded values are significant for $P < 0.05$.

postoperative month 1 to month 3 in the WaveLight group or the Technolas group ($P > 0.05$).

At postoperative month 3, 70% of patients in the WaveLight group and 100% of patients in the Technolas group had UDVA of 20/25 or better ($P = 0.211$) (Table 5; Figure 4). At month 1, two eyes lost ≥1 line(s) of CDVA and 3 eyes gained ≥1 line(s) of CDVA in the WaveLight group (n = 14). In the Technolas group 2 eyes lost 1 line of CDVA and 5 eyes gained ≥1 line(s) of CDVA (n = 23) (Figure 5). At month 3, none of the eyes lost any lines of CDVA and 2 eyes gained ≥2 lines of CDVA in the WaveLight group (n = 7). In the Technolas group at month 3, none of the eyes lost any lines of CDVA and 2 eyes gained ≥1 line(s) of CDVA (n = 9) (Figure 5). No significant differences were observed between the two groups regarding the loss or gain of lines of CDVA at month 1 and month 3 ($P > 0.05$).

At month 1 in the WaveLight vs. the Technolas group, spherical equivalent refraction was within ±0.50 D of emmetropia in 14 patients (73.7%) vs. 17 patients (73.9%) ($P = 1.000$), and the cylinder was within ±0.50 D in 7 patients (36.8%) vs. 10 patients (43.5%) ($P = 0.757$) (Table 6), respectively. At month 3 in the WaveLight vs. the Technolas group, spherical equivalent refraction was within ±0.50 D of emmetropia in 4 patients (40%) vs. 7 patients (77.8%) ($P = 0.170$), and the cylinder was within ±0.50 D in 1 patient (10%) vs. 3 patients (33.3%) ($P = 0.303$) (Table 6), respectively. The relationships between attempted and achieved corrections in the WaveLight group and the Technolas group at month 3 are shown in Figure 6.

At month 3, safety was 1.09 ± 0.17 (1.00–1.43) for the WaveLight group and 1.06 ± 0.14 (1.00–1.43) for the Technolas group ($P = 0.728$). At month 3, efficacy was 1.18 ± 0.48 (0.90–2.50) for the WaveLight group and 1.00 ± 0.08 (0.90–1.14) for the Technolas group ($P = 0.637$). No intraoperative or postoperative complications were reported for either group.

Table 5. Cumulative visual acuities at month 1 and month 3 postoperatively in the WaveLight and Technolas groups.

Follow-up visits	Visual acuities	WaveLight	Technolas	P
Post-op month 1	n	19	23	
	UDVA ≥ 20/20	6 (31.6%)	7 (30.4%)	1.000
	UDVA ≥ 20/25	13 (68.4%)	17 (73.9%)	0.742
	UDVA ≥ 20/32	14 (73.7%)	19 (82.6%)	0.707
Post-op month 3	n	10	9	
	UDVA ≥ 20/20	2 (20%)	3 (33.3%)	0.628
	UDVA ≥ 20/25	7 (70%)	9 (100%)	0.211
	UDVA ≥ 20/32	7 (70%)	9 (100%)	0.211

UDVA: uncorrected distance visual acuity.
P: Fisher's exact test.

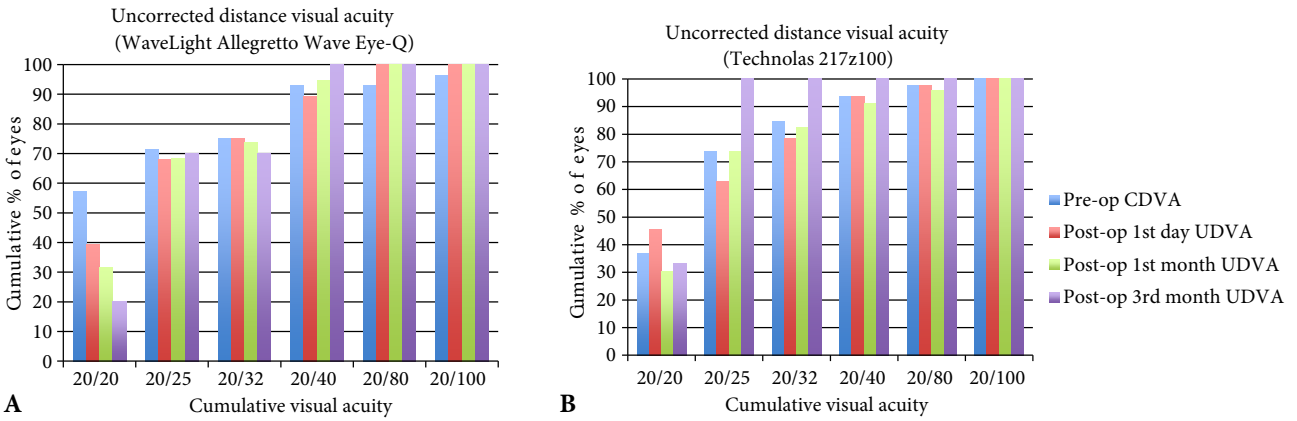

Figure 4. Preoperative and postoperative cumulative visual acuities of patients in the WaveLight and Technolas groups. A: WaveLight group; B: Technolas group.

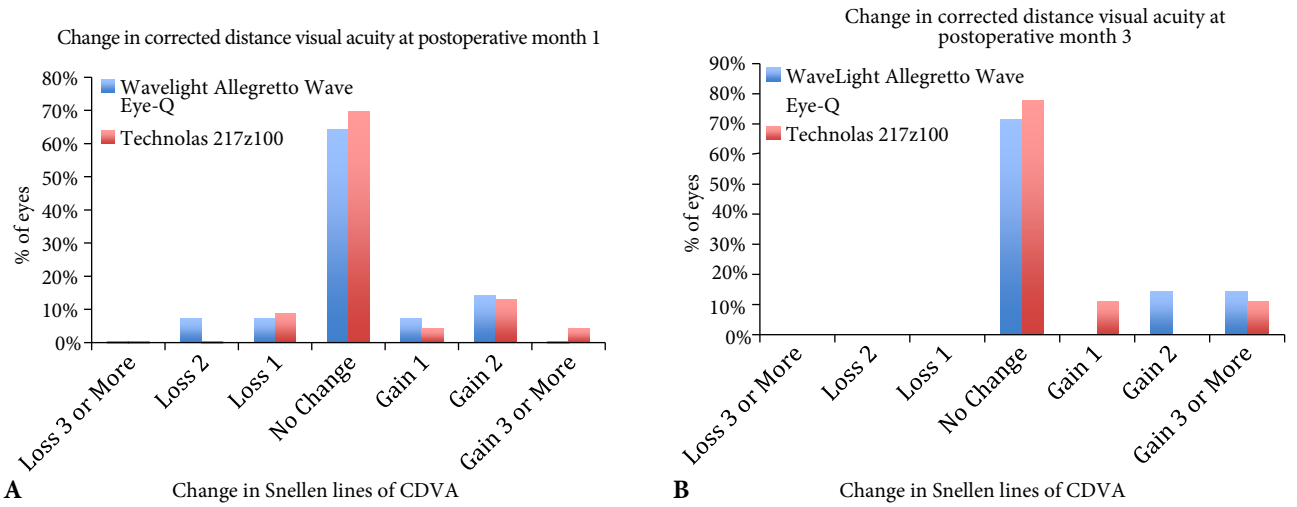

Figure 5. Change in the corrected distance visual acuity at postoperative month 1 and month 3 in the WaveLight and Technolas groups. A: Month 1; B: Month 3.

Table 6. Refractive results after laser in situ keratomileusis in the WaveLight and Technolas groups.

Follow-up visits	Refractive results	WaveLight	Technolas	P
Post-op day 1	n	28	44	
	Eyes within ±0.50 D SE	13 (46.4%)	28 (63.6%)	0.222
	Eyes within ±1.00 D SE	18 (64.3%)	44 (100%)	0.000
	Eyes within ±0.50 D cylinder	12 (42.9%)	22 (50%)	0.632
Post-op month 1	n	19	23	
	Eyes within ±0.50 D SE	14 (73.7%)	17(73.9%)	1.000
	Eyes within ±1.00 D SE	16 (84.2%)	23 (100%)	0.084
	Eyes within ±0.50 D cylinder	7 (36.8%)	10 (43.5%)	0.757
Post-op month 3	n	10	9	
	Eyes within ±0.50 D SE	4 (40%)	7 (77.8%)	0.170
	Eyes within ±1.00 D SE	9 (90%)	9 (100%)	1.000
	Eyes within ±0.50 D cylinder	1 (10%)	3 (33.3%)	0.303

D: diopter; SE: spherical equivalent.
P: Fisher's exact test. Bolded values are significant at $P < 0.05$.

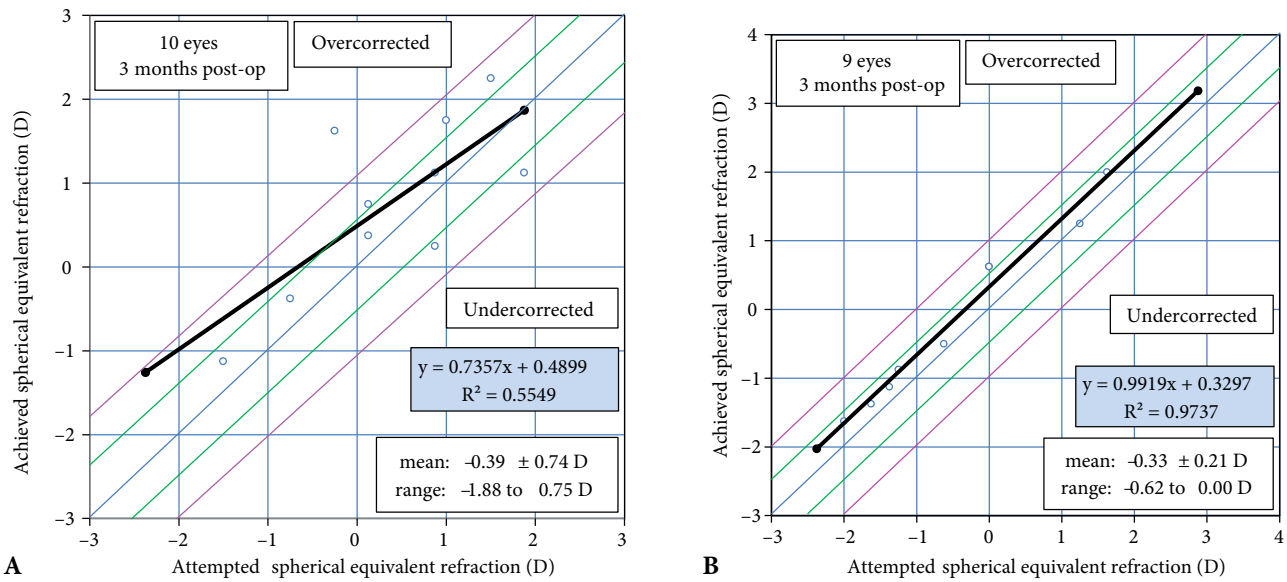

Figure 6. Attempted vs. achieved spherical equivalent refraction at postoperative month 3 in the WaveLight and Technolas groups. A: WaveLight group; B: Technolas group.

4. Discussion

Mixed astigmatism can be surgically managed by astigmatic keratotomy and/or LASIK. However, poor predictability (5–8) and complications of astigmatic keratotomy led refractive surgeons to use LASIK as a standard surgical option. There are different techniques for LASIK correction of mixed astigmatism, including negative-cylinder nomogram, positive-cylinder nomogram, bitoric ablation, cross-cylinder ablation, and sequential ablation. In a negative-cylinder nomogram central ablation is performed along the steepest meridian. This also induces some flattening of the flattest meridian (2). In a positive-cylinder nomogram, the flattest meridian is steepened. Since ablation is not performed in the central

cornea, no significant effect on the steepest meridian is observed (9). The bitoric ablation technique flattens the steepest meridian with a central cylindrical ablation and steepens the flattest meridian with a paracentral ablation. This technique has the advantages of correcting the same refractive error with less tissue removal (10). In cross-cylinder ablation the treatment is split into three parts: two symmetrical cylinder treatments of opposed signs (a negative and a positive cylinder in equal parts), followed by a spherical component treatment (11). In the sequential ablation technique, the positive cylinder is treated first and full astigmatism is corrected. A purely myopic eye is obtained and then the negative sphere is treated (2).

Different laser systems use these techniques aiming at less tissue ablation with better postoperative visual and refractive results. Postoperative spherical equivalent values within 0.50 D or 1.00 D, cylindrical values within 0.50 D, and efficacy of ≥1.00 generally mean good visual outcomes (12–15). To date, for LASIK treatment of mixed astigmatism the results of one laser system (2,8,9,14,16–19) or two related laser systems (1,20) have been reported. In the present study we compared the early clinical outcomes of two different laser systems in treating mixed astigmatism for the first time in the literature.

Stonecipher et al. (1) reported that 81% (n = 21) of eyes had UDVA of 20/20 or better with the WaveLight Allegretto Wave 400 Hz excimer laser at postoperative month 3. Albarran-Diego et al. (9) reported that 21% of eyes treated with the Chiron Technolas 217 excimer laser had UDVA of 20/20 or better following surgery. In the present study, the frequency of postoperative UDVA of ≥20/20 was 31.6% and 20% in the WaveLight group and 30.3% and 33.3% in the Technolas group at postoperative month 1 and month 3, respectively. The postoperative low visual acuities may be attributed to the relatively higher preoperative cylindrical errors. We also found that UDVA following surgery was better than CDVA prior to surgery. At postoperative month 3, the mean efficacy was ≥1.00 for both the WaveLight and the Technolas groups. Pinelli et al. (2) reported that the efficacy was ≥1.00 in all eyes with the Technolas 217 excimer laser.

In the present study at month 3, none of the eyes lost any lines of CDVA and 2 eyes (28.5%) gained ≥2 lines of CDVA in the WaveLight group. In the Technolas group, none of the eyes lost any lines of CDVA and 2 eyes (20%) gained ≥1 line(s) of CDVA. Stonecipher et al. (1) reported that at 3 months postoperatively, no eyes lost any lines of CDVA and 3 eyes (12%) gained 1 line with the WaveLight Allegretto Wave 400 Hz excimer laser. Pinelli et al. (2) reported that there was no loss of lines of CDVA and 16 (40%) eyes gained 1 line in CDVA at postoperative 1 year with the Technolas 217 excimer laser.

In the present study from month 1 to month 3, there was a tendency of myopic regression in the mean spherical equivalent refraction in the WaveLight group (from –0.10 ± 0.58 D at month 1 to –0.29 ± 0.80 D at month 3) and myopic regression in the mean cylinder in the Technolas group (from –0.66 ± 0.43 D at month 1 to –0.88 ± 0.46 D at month 3), but these were not significant (Table 4; P = 0.057 and P = 0.150, respectively). Although not significant, these regressions may be clinically important and additional research with a larger population is required to more clearly discern if this is true.

All eyes had a mean spherical equivalent refraction within ±0.50 D of the intended correction and the residual astigmatism was ≤0.50 D in all eyes treated with the WaveLight Allegretto Wave 400 Hz in the study by Stonecipher et al. (1). Pinelli et al. (2) reported that 80% of patients (n = 32) treated with the Technolas 217 excimer laser had no residual astigmatism (≤0.50 D) and the remaining 20% (n = 8) had residual astigmatism between 0.50 D and 1.00 D. We found that at postoperative month 3, one eye in the WaveLight group and 3 eyes in the Technolas group had no residual astigmatism (P = 0.213). Spherical equivalent values were –0.38 ± 0.73 D in the WaveLight group and –0.33 ± 0.20 D in the Technolas group (P = 0.562). Although not significant, there was a tendency of myopic undercorrection of the spherical equivalent refraction in the WaveLight group (Table 2). Moreover, after excluding the patients with preoperative cylinder refraction of ≥5.00 D, analyses showed that the patients in the Technolas group had a tendency to have higher residual astigmatism at postoperative month 1 and month 3 (Table 3). These findings may be clinically significant and must be further evaluated with additional research with a larger population.

In conclusion, the results presented in the present study indicate that both laser systems are effective and safe for the correction of mixed astigmatism. In terms of surgical technique, none of the laser systems had an advantage over the other. The WaveLight Allegretto Wave Eye-Q 400 Hz excimer laser seems to have better refractive outcomes regarding cylindrical refraction, and the Technolas 217z100 excimer laser seems to have better outcomes regarding spherical equivalent refraction. However, a larger group of patients with a longer follow-up period is necessary to more clearly discern if this is true and to compare the stability of the results of these laser systems.

Acknowledgments

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