• Clinical Research •

Comparison of visual performance recovery after thin-flap LASIK with 4 femtosecond lasers

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Abstract

● **AIM: To compare the speed of visual recovery following myopic thin-flap LASIK with four femtosecond lasers.**

● **METHODS: Eighty-eight eyes of 46 patients who were consecutively scheduled for bilateral LASIK with the IntraLase FS60 (Group 1), Femto LDV Crystal Line (Group 2), Wavelight FS200 (Group 3) and VisuMax (Group 4) femtosecond lasers were enrolled in. Monocular uncorrected distance visual acuity (UDVA), best-corrected distant visual acuity (CDVA), refraction, contrast sensitivity and higher-order aberrations (HOAs) were evaluated at 1, 3d, 1wk and 1mo postoperatively.**

● **RESULTS: Sixteen eyes (72.7%) achieved 20/16 and 8 eyes (36.4%) were 20/12.5 at 1d in Group 2, which was significantly more than other 3 groups. At 1wk, 20 eyes (90.9%) achieved 20/16 in Groups 2 and 4. At 1mo, 20 eyes (90.9%) achieved 20/16 in Group 2 and Group 4, which were significantly more than other two groups. While by 1 mo, the difference of the residual spherical equivalent (SE) was not statistically significant among 4 groups (*P*=0.121). The induction of spherical aberration (SA) were significantly less for Groups 2, 3, 4 than for Group 1 one day after surgery (*P*=0.015). The differences among 4 groups were not statistically significant before and after surgery on every time points (all *P*>0.05).**

● **CONCLUSION: The thin-flap LASIK procedure using the Femto LDV Crystal Line and VisuMax femtosecond laser show faster visual performance recovery.**

● **KEYWORDS:** LASIK; femtosecond laser; refraction; visual recovery

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INTRODUCTION

Until recently, femtosecond lasers have primarily been used as an alternative to the microkeratome to cut thinner and planar corneal flaps in LASIK[1-3]. Thin-flap LASIK as treatment of myopia is considered one of the most successful surgical procedures overall, with a patient satisfaction rate of 95%[4]. One distinct advantage of thin-flap LASIK is the speed with which patients regain their vision postoperatively, while surface ablation is associated with slower recovery and increased risk of haze[5]. As refractive surgeons, we are accustomed to seeing recipients of thin-flap LASIK achieve uncorrected distance visual acuity (UDVA) of 20/20 or better by 1wk and even 1d following LASIK[6-7], however, the comparison of the speed of visual performance recovery after thin-flap LASIK with different 4 types of femtosecond laser has not been established.

The aim of this study is to compare and quantify the speed of visual performance recovery (included visual acuity, refraction, contrast sensitivity and corneal aberrations) in one month following myopia thin-flap LASIK with four types of femtosecond laser, which are the Abbott Medical Optics IntraLase FS60 femtosecond laser (Santa Ana Corp., California, USA), the Femto LDV Crystal Line femtosecond laser (Ziemer Group, Port, Switzerland), the Alcon WaveLight FS200 femtosecond laser (Fort Worth, TX, USA) and VisuMax femtosecond laser (Carl Zeiss Meditec AG, Jena, Germany).

SUBJECTS AND METHODS

Patients Data In this prospective pilot investigation, 88 eyes of 46 patients who were consecutively scheduled for bilateral LASIK treatment from February 2014 to March 2014 were enrolled in the Beijing Tongren Ophthalmic Center, Capital Medical University, Beijing, China. This study was reviewed & approved by the local ethics committee, and an informed consent was obtained from all the patients.

The treatment eligibility criteria were identical for four groups: a minimum age of 18y, stable myopia for at least 2y, a best-corrected distant Snellen visual acuity (CDVA) of 20/20 or better, and regular corneal topography. Patients with ocular pathology such as keratoconus, corneal scars, corneal dystrophies, an estimated residual stromal bed thickness of less than 250 μm, previous ocular surgery, glaucoma, diabetes, or systemic disease known to affect the eye were excluded.

Based on a randomization table, patients were assigned to IntraLase FS60 femtosecond laser (Group 1, 22 eyes with 12 patients) or FemtoLDV femtosecond laser (Group 2, 22 eyes with 12 patients) or WaveLight FS200 femtosecond laser (Group 3, 22 eyes with 11 patients) or VisuMax femtosecond laser (Group 4, 22 eyes with 11 patients). All patients had a bilateral simultaneous procedure. Our routine follow-up appointments were at 1, 3d, 1wk and 1mo.

Examination Procedure All patients underwent preoperative complete ocular examination to include measurement of the UDVA, CDVA, silt-lamp biomicroscopy of the anterior segment, intraocular pressure measurement with non-contact tomometer (NCT), ophthalmoscopy, objective refraction with the automatic refract-keratometry, manifest refraction and cycloplegic refraction, ultrasound pachymetry, corneal topography (TOMEY Inc., USA), anterior segment optical coherence tomography (OCT) (Optovue, Optovue Inc., Freemont, California, USA), wavefront aberration and contrast sensitivity measurements.

The higher order aberrations (HOAs) were measured by using WaveScan Wavefront aberrometer (VISX Inc., Santa Clara, USA) based on the principle of the Harmann-Shack wavefront sensor technigue[8]. All HOAs were measured in the natural scotopic condition after 10min dark adaptation. A skilled doctor (Zhang J) performed three examinations on the same eye with a 6-mm pupil diameter. The patient was instructed to blink prior to capture of the corneal image to avoid tear accumulation and tear film break. The best image was chosen for analysis if "good" repeatability.

The following parameters were recorded and analyzed: 1) the root mean square of HOAs from 3rd to 6th orders (RMS3-6); 2) RMS of 3rd coma (square root of the sum of the squared coefficients of Z_3^{-1} and Z_3^{1}), trefoil (Z_3^{-3} and Z_3^{3}), 4th order spherical aberration (Z_4^{0}) and RMS of total higher order aberrations (RMSh).

Contrast sensitivity with and without glare was measured by using Optec 6500 Vision Tester (Stereo Optical Co. Inc., USA) under scotopic (3 cd/m^2) lighting conditions. All patients were examined for monocular contrast sensitivity and were measured with corrected spherical and cylindrical lens according to the manifest refraction in the natural scotopic condition after dark adaptation. The spatial frequencies at which contrast sensitivity was examined were 1.5, 3, 6, 12, 18 cycles per degree (cpd), and contrast sensitivity was expressed in logarithmic units.

Postoperative examinations were performed at 1, 3d, 1wk and 1mo after surgery. At each of these time periods UDVA, CDVA, objective refraction with the automatic refract-keratometry, manifest refraction, anterior segment OCT, wavefront aberration and contrast sensitivity were performed.

Surgical technique The same experienced surgeon (Zhou YH) performed all LASIK procedures using topical anesthesia. All four femtosecond lasers were programmed to a flap thickness of 110 μm.

In Group 1, the flap was created using the IntraLase FS60 femtosecond laser. The laser energy was 0.75 μJ with a repetition frequency of 60 kHz. The pulse duration was between 600 and 800 femtosecond. The line and spot separations were 8.0 μm.

In Group 2, the flap was created by FemtoLDV Crystal Line femtosecond laser. The laser energy was <10 nJ pulse energy with a frequency higher than 5 MHz. The pulse duration was between 200 and 350 femtosecond. The line and spot separations were <2.0 μm.

In Group 3, the flap was created using the WaveLight FS200 femtosecond laser. The laser energy was 0.8 μJ with a repetition frequency of 200 kHz. The pulse duration was about 350 femtosecond. The line and spot separations were 8.0 μm. A flap of 8.5 mm diameter was created with a superior hinge in all eyes from Groups 1, 2 and 3.

In Group 4, the flap was created using the VisuMax femtosecond laser. The laser energy range was 135 nJ to 150 nJ with a repetition frequency of 500 kHz. The pulse duration was between 220 and 580 femtosecond. Superior hinged flaps were created with 7.9 mm diameter. The spot-line separation was set at 5.0 μm for flap and 2.0 μm for flap side cut. The side-cut was at an angle of 90°.

After the flap was lifted, ablations were performed using the VisxS4 excimer laser (VISX Inc., Santa Clara, USA) in four groups with a 6.0 mm optical zone and 0.5 mm transition zone. The corneal flaps and stromal surfaces were irrigated with a balanced normal salt solution, and the flaps were repositioned. After surgery, patients were instructed to instill fluorometholone 0.1% 4 times a day for 3d which was tapered over 2wk. Levofloxacin and artificial tears 4 times per day for 2wk were also given.

Data Analysis The data was expressed as the mean±SD and analyzed with SPSS software (version 17.0, USA). The UDVA, CDVA, manifest refraction, wavefront aberration and contrast sensitivity were treated as continuous variables. One-way analysis of variance (ANOVA) was used to compare differences between baseline characteristics and analyze conformance of measurement data to normal distribution. The Wilcoxon signed-rank test was applied to identify the measurement data not conforming to normal distribution. A P<0.05 was considered statistically significant.

RESULTS

Eighty-eight eyes from 46 consecutive patients were evaluated. Table 1 shows the baseline demographics of the patients. No

Table 1 Preoperative demographics of patients mean±SD

Parameters	Group 1	Group 2	Group 3	Group 4	^{a}P
Eyes (*n*)	22	22	22	22	—
Age (a)	27.33±6.24	24.08±5.04	24.09±6.19	26.91±5.21	0.214
UDVA (logMAR)	-0.94±0.37	-1.06±0.31	-1.08±0.26	-0.97±0.25	0.111
BCVA (logMAR)	0.05±0.04	0.07±0.06	0.07±0.04	0.08±0.03	0.154
SE (D)	-4.59±1.64	-4.94±1.57	-4.83±0.94	-4.51±1.06	0.102
CCT (μm)	530.55±25.41	540.23±24.04	538.86±23.08	532.59±21.59	0.164
Corneal curvature (D)	43.88±1.31	43.12±1.35	43.41±1.75	42.79±1.44	0.101
IOP (mm Hg)	16.41±3.16	15.82±2.82	14.68±2.83	15.09±2.16	0.175

UDVA: Uncorrected distance visual acuity; BCVA: Best corrected visual acuity; CCT: Central corneal thickness; SE: Spherical equivalent; IOP: Intraocular pressure. [a]One-way analysis of variance (ANOVA).

significant differences were observed between Group 1, Group 2, Group 3 and Group 4 (all *P*>0.05).

Visual Acuity and Refraction Eyes were compared by logMAR and converted to Snellen notation. In terms of monocular distance UDVA, all of the eyes in our study achieved 20/25 at 1d and only all the eyes in Group 2 achieved 20/20 at 1d. Sixteen eyes (72.7%) achieved 20/16 and 8 eyes (36.4%) were 20/12.5 at 1d in Group 2, which was significantly more than other 3 groups. At 1wk, 20 eyes (90.9%) achieved 20/16 in Groups 2 and 4. At 1mo, 20 eyes (90.9%) achieved 20/16 in Group 2 and Group 4, which are significantly more than other two groups. Monocular UDVA results at defined study time points are summarized in Table 2. For monocular CDVA, 22 eyes (100%) of eyes achieved 20/20 by 1wk and 1mo after surgery. One day after surgery, 17 eyes (77.3%) achieved 20/16 and 22 eyes (100%) achieved 20/20 in Group 2, while 14 eyes (63.6%) achieved 20/16 and 21 eyes (95.5%) achieved 20/20 in Group 4, which were obviously better than other two groups (Figure 1, Table 2).

The mean postoperative spherical equivalent (SE) decreased to 0.31±0.51 D in Group 1, 0.15±0.39 D in Group 2, 0.01±0.47 D in Group 3, -0.15±0.50 D in Group 4 one day after surgery (*P*=0.005). By 1d, the residual SE in Group 3 was statistically significant less than other 3 groups. While by 1mo, the difference of the residual SE was not statistically significant among 4 groups (*P*=0.121, Table 3).

Higher-order Aberrations Table 4 displays HOA before and after surgery. The RMSh, coma and spherical aberration (SA) significantly increased, while the trefoil didn't change after surgery in 4 groups. The induction of SA were significantly less for Groups 2, 3, 4 than for Group 1 one day after surgery (*P*=0.015; Group 2: the RMS value of 0.11 to 0.17 μm; Group 3: 0.11 to 0.15 μm; Group 4: 0.13 to 0.17 μm; Group 1: 0.12 to 0.23 μm). While, the induction of SA were significantly less for Group 4 than for Groups 1, 2 and 3 three days after surgery (*P*=0.021; Group 4: the RMS value of 0.13 to 0.17 μm; Group 1: 0.12 to 0.22 μm; Group 2: 0.11 to 0.23 μm; Group 3: 0.11 to 0.21 μm). The differences of other RMS value of HOAs among 4 groups were not significant (all *P*>0.05).

Table 2 Uncorrected distance visual acuity at measured time points Cumulative percentage of patients (%)

UDVA	20/12.5 or better	20/16 or better	20/20 or better	20/25 or better
Group 1				
1d	32.8	50	90.9	100
3d	49.9	68.2	95.5	100
1wk	50	77.3	100	100
1mo	59.1	81.8	100	100
Group 2				
1d	36.4	72.7	100	100
3d	54.5	81.8	100	100
1wk	58.6	90.9	100	100
1mo	63.2	90.9	100	100
Group 3				
1d	31.8	45.5	86.4	100
3d	36.4	77.3	100	100
1wk	40.9	81.8	100	100
1mo	54.5	81.8	100	100
Group 4				
1d	31.8	63.6	95.5	100
3d	40.9	81.8	100	100
1wk	45.5	90.9	100	100
1mo	54.5	90.9	100	100

Contrast Sensitivity Monocular mesopic contrast sensitivity data with and without glare are presented in Figure 2. Preoperative values are with spectacle correction while postoperative testing was performed on uncorrected eyes. Monocular mesopic contrast sensitivity with and without glare was restored to preoperative baseline by 1d after surgery (all *P*>0.05). By 3d after surgery, the contrast sensitivity of 1.5 cpd with glare showed a statistically significant improvement over preoperative baseline in Groups 2, 3 and 4 (*P*=0.039, 0.006, 0.009), and that was maintained at the 1-month visit. The differences among 4 groups were not statistically significant before and after surgery on every time points (all *P*>0.05).

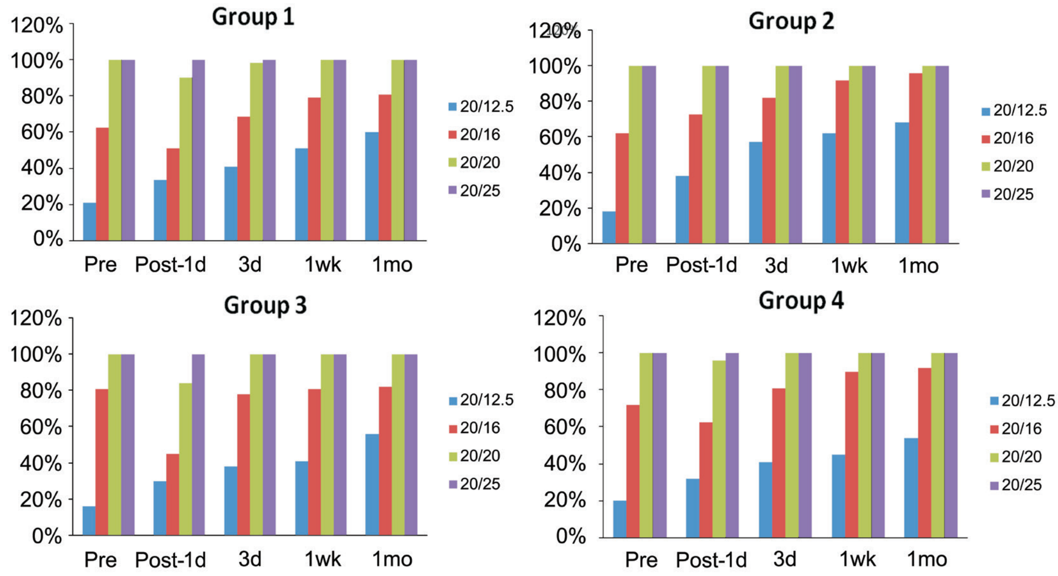

Figure 1 Monocular recovery of best corrected visual acuity of 4 groups.

Table 3 Comparison of refraction results among 4 groups mean±SD; D

Time points	Group 1	Group 2	Group 3	Group 4	*P*
Preoperatively	-4.59±1.64	-4.94±1.57	-4.83±0.94	-4.51±1.06	0.102
1d	0.31±0.51	0.15±0.39	0.01±0.47	-0.15±0.50	0.005
3d	0.35±0.51	0.10±0.39	0.11±0.34	-0.24±0.46	<0.001
1wk	0.05±0.59	0.02±0.56	-0.19±0.45	-0.19±0.45	0.303
1mo	0.11±0.45	0.03±0.51	-0.15±0.47	-0.21±0.42	0.121

Table 4 Preoperative and postoperative higher-order aberrations in 4 groups mean±SD

HOA	RMSh	Coma	Trefoil	SA	RMS3	RMS4	RMS5	RMS6
Group 1								
Preop.	0.39±0.15	0.19±0.11	0.17±0.11	0.12±0.15	0.26±0.11	0.21±0.15	0.09±0.04	0.07±0.02
1d	0.46±0.12	0.26±0.13	0.16±0.07	0.23±0.14[a]	0.31±0.11	0.27±0.12	0.13±0.05	0.09±0.04
3d	0.48±0.12	0.27±0.13	0.16±0.09	0.22±0.12[a]	0.31±0.11	0.27±0.11	0.12±0.04	0.09±0.03
1wk	0.45±0.14	0.26±0.13	0.16±0.08	0.23±0.15	0.31±0.12	0.29±0.13	0.12±0.06	0.09±0.05
1mo	0.45±0.13	0.25±0.14	0.16±0.08	0.21±0.12	0.31±0.12	0.27±0.12	0.12±0.06	0.09±0.04
Group 2								
Preop.	0.35±0.11	0.16±0.09	0.17±0.11	0.11±0.06	0.24±0.11	0.15±0.06	0.07±0.03	0.07±0.04
1d	0.45±0.16	0.28±0.17	0.16±0.08	0.17±0.11[a]	0.34±0.15	0.23±0.11	0.12±0.06	0.09±0.04
3d	0.49±0.14	0.29±0.15	0.18±0.08	0.23±0.14[a]	0.37±0.15	0.29±0.13	0.12±0.05	0.08±0.03
1wk	0.49±0.16	0.29±0.15	0.15±0.08	0.25±0.15	0.35±0.14	0.29±0.14	0.11±0.03	0.09±0.04
1mo	0.48±0.15	0.27±0.16	0.15±0.08	0.22±0.13	0.33±0.15	0.28±0.11	0.12±0.05	0.09±0.05
Group 3								
Preop.	0.35±0.14	0.16±0.11	0.14±0.07	0.11±0.11	0.22±0.11	0.19±0.12	0.08±0.07	0.06±0.02
1d	0.47±0.14	0.29±0.12	0.15±0.08	0.15±0.12[a]	0.34±0.13	0.22±0.11	0.12±0.06	0.09±0.04
3d	0.47±0.16	0.28±0.14	0.15±0.09	0.21±0.16[a]	0.33±0.14	0.25±0.15	0.13±0.05	0.09±0.04
1wk	0.47±0.16	0.30±0.14	0.15±0.07	0.20±0.15	0.34±0.13	0.23±0.15	0.14±0.05	0.09±0.04
1mo	0.46±0.17	0.28±0.13	0.15±0.09	0.20±0.14	0.34±0.14	0.24±0.13	0.13±0.04	0.09±0.04
Group 4								
Preop.	0.36±0.09	0.19±0.09	0.15±0.07	0.13±0.09	0.26±0.09	0.19±0.06	0.09±0.05	0.06±0.03
1d	0.49±0.13	0.29±0.17	0.18±0.08	0.17±0.12[a]	0.37±0.11	0.26±0.11	0.12±0.05	0.08±0.04
3d	0.48±0.13	0.30±0.15	0.15±0.08	0.17±0.12[a]	0.37±0.14	0.25±0.15	0.13±0.05	0.09±0.04
1wk	0.49±0.13	0.31±0.17	0.15±0.08	0.25±0.11	0.38±0.14	0.27±0.09	0.11±0.05	0.09±0.05
1mo	0.47±0.14	0.29±0.17	0.15±0.07	0.21±0.11	0.35±0.16	0.26±0.14	0.12±0.04	0.09±0.04

[a]$P<0.05$.

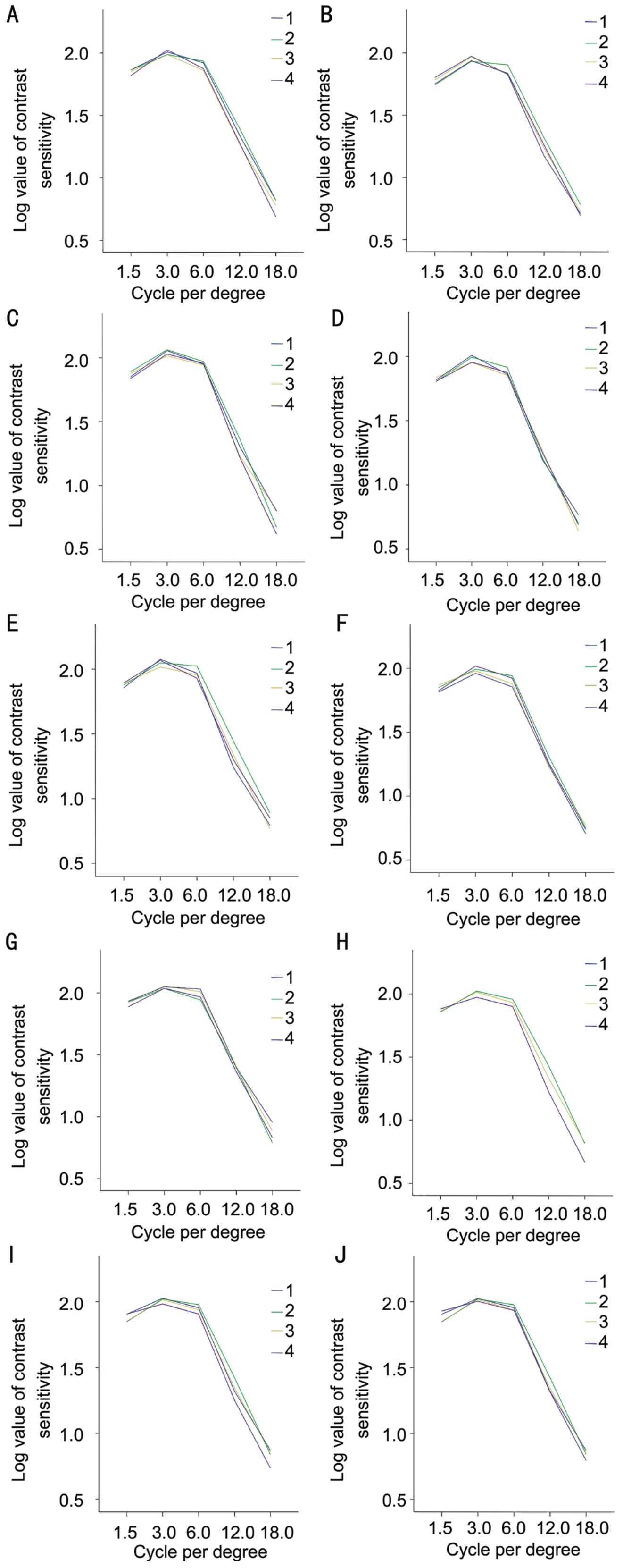

Figure 2 Monocular mesopic contrast sensitivity (CS) of four groups A: CS without glare before surgery; B: CS with glare before surgery; C: CS without glare 1d after surgery; D: CS with glare 1d after surgery; E: CS without glare 3d after surgery; F: CS with glare 3d after surgery; G: CS without glare 1wk after surgery; H: CS with glare 1wk after surgery; I: CS without glare 1mo after surgery; J: CS with glare 1mo after surgery.

DISCUSSION

The femtosecond laser offers several advantages over microkeratomes for corneal flap creation because of better safety, reproducibility, and predictability. Some studies[8-10] compared different femtosecond lasers for corneal flap creation during LASIK, and found that different femtosecond laser systems produced different flap configurations depending on their individual mechanisms. Thus, the visual outcomes depending on flap configuration may different in patients used different femtosecond laser systems.

The IntraLase was the first commercial available femtosecond laser since 2001. Since then, other femtosecond lasers have become commercially available. These include the Femto LDV, VisuMax and WaveLight FS200. Fortunately, our ophthalmic center already has 4 types of femtosecond lasers, and it is the first study to compare the speed of visual performance recovery after thin-flap LASIK with different 4 types of femtosecond laser.

Standard (not wavefront-guided) femtosecond-LASIK would be beneficial to evaluate the effect of femtosecond-laser flap creation in decreasing the optical side effects and HOAs reported after LASIK with mechanical-microkeratome flap creation[11]. In the present study, 72.7% eyes achieved 20/16 and 36.4% eyes were 20/12.5 at 1d with the Femto LDV Crystal Line femtosecond laser, which was significantly more than other 3 femtosecond lasers. At 1wk and 1mo after surgery, more eyes achieved 20/16 with the Femto LDV Crystal Line and VisuMax femtosecond lasers than other 2 femtosecond lasers. By 1d, the residual SE in eyes with the Alcon WaveLight FS200 femtosecond laser was statistically significant less than other 3 groups. While by 1mo, the difference of the residual SE was not statistically significant among 4 groups. Our refractive and visual acuity outcomes agree with previously published studies of myopic LASIK using a femtosecond laser at the same postoperative days[12].

It's reported that the corneal flap creation could increase lower-order, as well as HOAs which could negatively affect postoperative vision performance[13-15]. In the present study, the induction of SA were significantly less for eyes with Femto LDV Crystal Line, WaveLight FS200 and VisuMax femtosecond lasers than for eyes with IntraLase FS60 femtosecond laser one day surgery. While, the induction of SA were significantly less for eyes with VisuMax femtosecond laser than for eyes with other 3 femtosecond lasers three days after surgery. However, the newer generation of Intralase FS150 has shorter pulse duration but a higher repetition rate and may result in better visual performance.

Previous studies have documented a decrease in contrast sensitivity correlated with increased higher order aberrations after thin-flap LASIK[16-17]. In the present study, we observed monocular mesopic contrast sensitivity with and without glare was restored to preoperative baseline by 1d after surgery. However, the differences among 4 groups were not statistically significant before and after surgery on every time points.

Studies suggest that the speed of visual recovery following LASIK is related to the smoothness of optical interface cleaved by the femtosecond laser during the flap-making process[18-19]. Riau *et al*[20] found that the nJ-energy pulses produced minimal wound healing reaction and apoptotic cells along the incision plane. The application of an nJ-energy laser, which can incise the cornea without inducing significant damage to cells and wound healing reaction, offers great potential at reducing scarring following incisional laser stromal surgery. The Femto LDV Crystal Line femtosecond laser has the pulse rate faster than 5 MHz, and the pulse energy is an nJ-energy, the water vapor can still be present in the bubble when the bubble opens during flap lifting. So the stromal bed is smoother and less traumatic tissue dissection would happen in the Femto LDV Crystal Line femtosecond laser group. So the speed of visual recovery for eyes with Femto LDV Crystal Line femtosecond laser was faster than other femtosecond lasers.

Another key difference among the 4 femtosecond laser platforms is the applanation surface during suction before the application of the femtosecond laser to create the LASIK flaps. The IntraLase, Femto LDV and WaveLight femtosecond lasers use a flat applanation surface, while the VisuMax femtosecond laser uses a curved interface that does not flatten the cornea before the femtosecond laser process. The flattening of the cornea by the flat applanation surface of the IntraLase, Femto LDV and WaveLight femtosecond laser platforms cause horizontal deformation of the cornea during the femtosecond laser procedure. Therefore, it is possible for the laser pulses to create a linear flap parallel to the corneal surface and thus create a regular planar flap. In contrast, the VisuMax femtosecond laser platform, which uses a curved corneal interface, allows the cornea to remain in a more natural state during the femtosecond laser procedure. However, the femtosecond laser pulses have to be applied in a curved plane parallel to the cornea surface to create a planar corneal flap. That means VisuMax system may be advantageous for procedures requiring intrastromal beam localization under natural corneal curvature, and it also creates planar and uniform corneal flaps during LASIK.

In summary, the thin-flap LASIK procedure using the Femto LDV Crystal Line and VisuMax femtosecond laser showed faster visual performance recovery. It might be due to the smoothness of the optical interface created by these lasers. Further study with a lager sample of eyes is required to corroborate these findings.

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