Int J Clin Exp Med 2016;9(11):22375-22380
www.ijcem.com /ISSN:1940-5901/IJCEM0034556

Original Article

Comparison of different femtosecond laser refractive surgeries on higher-order aberrations

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Received June 28, 2016; Accepted September 5, 2016; Epub November 15, 2016; Published November 30, 2016

Abstract: This study aimed to investigate the effects of femtosecond laser-assisted in situ keratomileusis (FS-LASIK) and small incision lenticule extraction (SMILE) on higher-order aberrations in patients. 56 cases (112 eyes) undergoing refractive surgery in our hospital were selected in this study, all patients were randomly divided into femtosecond laser-assisted in situ keratomileusis group (LASIK group) and small incision lenticule extraction group (SMILE group) with each group of 28 patients (56 eyes) by random digital table method. Higher-order aberrations of anterior corneal surface, including total higher-order aberration, spherical aberration, horizontal coma and vertical coma were detected at different time points (the 1st week, 1st month, 3rd month and 6th month) before and after surgery, and the changes between preoperative and postoperative values were compared. Postoperative total higher-order aberrations and spherical aberrations at different time points in both groups were significantly increased while vertical coma was obviously decreased when compared with preoperative data ($P<0.05$). Postoperative horizontal coma at different time points in SMILE group was increased ($P<0.05$) while there was no significant change in horizontal coma in LASIK group ($P>0.05$). Both postoperative total higher-order aberrations and spherical aberrations at different time points and their change values before and after surgery in SMILE group were significantly lower than those in LASIK group ($P<0.05$). In conclusion, changes in higher-order aberrations induced by femtosecond laser-assisted SMILE are less than that induced by FS-LASIK, so the visual quality of patients can be improved in certain scenarios.

Keywords: Femtosecond laser, small incision lenticule extraction, in situ keratomileusis, higher-order aberrations

Introduction

Femtosecond (1 fs=10^{-15} s) laser refers to a kind of infrared laser operated in pulse shapes, and ophthalmologists have gradually realized that greater importance is attached to its assistance on corneal refractive surgery in recent years [1]. Femtosecond laser is most commonly applied to making corneal flaps in laser in situ keratomileusis (LASIK) and making stromal lenticule in small incision lenticule extraction (SMILE). Both surgeries for the treatment of refractive errors, such as myopia, hyperopia, astigmatism, have higher safety and accuracy [2, 3]. The wave front aberration mainly results from refractive media, such as the cornea, lens and vitreous, together with lower-order and higher-order aberrations, is the most vital factor in eye imaging quality [4]. This study aimed to analyze changes in postoperative higher-order aberrations of patients undergoing two femtosecond-assisted SMILE or LASIK surgery.

Subjects and methods

General information

56 cases (112 eyes) undergoing refractive surgery in the department of ophthalmology were selected from January to June 2013 for this study, including 25 males and 31 females. They aged 18-40 with the average age of 26.3±7.1. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of the Second People Hospital of Xinxiang. Written informed consent was obtained from all participants.

Inclusion criteria: (1) the corneal morphology of patient was normal, and the cornea was trans-

Table 1. Comparison of general information and preoperative examination results of patients in two groups

Groups	Cases	Eyes	Age	Male/Female	Uncorrected visual acuity	Best corrected visual acuity	Spherical equivalent (D)
SMILE group	28	56	25.9±6.2	14/14	0.13±0.09	1.05±0.49	-5.65±1.83
LASIK group	28	56	26.7±6.9	11/17	0.14±0.11	1.01±0.51	-5.61±1.85
t/χ^2			0.456	0.650	0.372	-0.300	0.115
P			0.325	0.420	0.356	1.674	0.454

parent without nebula or macula; (2) binocular refractive diopter of patient was stable, and the change was less than 0.5 D/year; (3) Before surgery, patients with soft contact lenses were required to discontinue for more than two weeks, while rigid contact lenses must be stopped to wear for more than a month; (4) patients were able to finish six months of follow up according to the research arrangement; (5) patients must sign the informed consent of this study.

Exclusion criteria: (1) patients combined with keratoconus, glaucoma, keratitis in active stage, and cataract were excluded; (2) patients with fundus diseases or optic neuropathy were excluded; (3) patients with previous history of ocular surgical or trauma were excluded; (4) patients with systemic connective tissue diseases or autoimmune diseases were excluded; (5) breast-feeding or pregnant female patients were excluded; (6) patients who were unable to complete the follow-up were excluded. 56 cases were randomly divided into femtosecond laser-assisted in situ keratomileusis group (LASIK group) and small incision lenticule extraction group (SMILE group) with each group of 28 patients (56 eyes) by random digital table method. There was no significant difference in age, gender, preoperative uncorrected visual acuity, best corrected visual acuity and spherical equivalent in the two groups (P>0.05; **Table 1**).

Preoperative preparation and surgical methods

Local application of 0.3% ofloxacin ophthalmic eye drops (4 times per day) was conducted to treat all cases, and eye cosmetics were prohibited before and the day of surgery. The surgeries of the two groups were conducted by the same experienced physician. After preoperative conventional washing of conjunctival sac, disinfection and draping, 0.4% oxybuprocaine were used to drop the eyes for ocular surface anesthesia with once/5 minutes, a total of 4 times.

In LASIK group, VisuMax femtosecond laser system (Carl Zeiss Company, Germany) was applied to making corneal flap with the pulse frequency of 500 kHz and the energy of 115 nJ. The main parameters for the surgery: the thickness and diameter of corneal flap was 8 mm and 110 μm respectively, and the cutting angle was set to 90°, as well as the pedicle was placed on the nasal side with the width angle of 50°. After laser scanning, corneal flap was fully uncovered, and then Allegretto Wave Eye. Q was applied to cutting the corneal stroma, and eyeball positioning system was used to monitor laser cutting procedures with the average optical diameter of 6.2 mm.

In SMILE group, VisuMax femtosecond laser system (Carl Zeiss Company, Germany) was also applied to making corneal flap and stromal lenticule with the pulse frequency of 500 kHz and the energy of 115 nJ. The main parameters for the surgery: the diameter and thickness of corneal cap was 7.2 mm and 110 μm respectively; the diameter of stromal lenticule was 6.2 mm; the hinge thickened 10 μm; the astigmatism transition zone was 0.1 mm. In the 12 o'clock position, 4~5 mm arc lateral incision was made with the angle of 65°-82°. When the cutting on the cornea with femtosecond laser scanning was finished, separated lenticule and superficial cornea, together with deep-layer stroma composed the independent lenticule and corneal flap. Finally, the lenticule was removed with microforceps.

After surgery, all patients received 0.3% ofloxacin eye drops for 2 days with 4 times/d, and 0.1% fluorometholone with 4 times/d, as well as 1 time was decreased for every two weeks until two months.

Table 2. Comparison of total higher-order aberrations of anterior corneal surface at different time points and the change values in two groups ($\bar{x}\pm s$)

Items	Groups	Before surgery	After surgery			
			The 1st week	The 1st month	The 3rd month	The 6th month
Average values	SMILE group	0.15±0.04	0.25±0.10	0.27±0.13	0.27±0.11	0.21±0.12
	LASIK group	0.14±0.06	0.29±0.13	0.32±0.14	0.34±0.15	0.26±0.11
t value		-1.038	1.825	1.958	2.816	1.839
P		0.151	0.013	0.026	0.003	0.034
Change values	SMILE group	-	0.11±0.06	0.10±0.07	0.10±0.07	0.06±0.06
	LASIK group	-	0.18±0.12	0.14±0.10	0.15±0.12	0.10±0.08
t value			3.904	2.296	3.771	-2.245
P			0.000	0.012	0.000	0.013

Table 3. Comparison of spherical aberrations of anterior corneal surface at different time points and the change values in two groups ($\bar{x}\pm s$)

Items	Groups	Before surgery	After surgery			
			The 1st week	The 1st month	The 3rd month	The 6th month
Average values	SMILE group	0.24±0.13	0.41±0.18	0.44±0.19	0.42±0.18	0.39±0.14
	LASIK group	0.23±0.12	0.53±0.21	0.56±0.23	0.59±0.26	0.56±0.20
t value		-0.423	3.247	3.010	4.023	5.211
P		0.337	0.000	0.002	0.000	0.000
Change values	SMILE group	-	0.7±0.08	0.10±0.07	0.08±0.06	0.07±0.06
	LASIK group	-	0.16±0.13	0.19±0.14	0.21±0.16	0.16±0.11
t value			4.412	2.869	5.693	3.444
P			0.000	0.002	0.000	0.000

High-order aberrations assay

Higher-order aberrations of anterior corneal surface of the two groups were detected with Pentacam anterior eye segment analysis system at preoperative and postoperative 1st week, 1st month, 3rd month and 6th month, which were conducted by the same skilled technician. Detection methods: in the darkroom, patient's mandible was placed on the chin underprop of Pentacam, and the eyes gazed at the bright blue light in natural pupil state. The operator focused on the images on the compute with the joystick according to the system prompts. After successful focus, the patient was asked to fast blink several times to evenly distribute tear film with 5-time measurement for each eye. Finally, only the results with imaging quality "OK" were collected, and the average values were calculated. In this study, measurement results for aberrations were converted and expressed as the corresponding Zernike coefficient root meansquare at the same pupil diameter (6 mm), which mainly consisted of total higher-order aberrations, spherical aberrations, horizontal coma and vertical coma [5].

Statistical analysis

All data were performed using SPSS 17.0 version software and measurement data was expressed as ($\bar{x}\pm s$). The count data of the normal distribution was compared with the t-test, while count data was analyzed with X^2 test. $P<0.05$ was considered statistically significant.

Results

Comparison of total higher-order aberrations and the change values before and after surgery in two groups

As shown in **Table 2**, postoperative total higher-order aberrations at different time points in both groups were significantly increased when compared with preoperative data ($P<0.05$). Postoperative total higher-order aberrations at different time points and the change values

Table 4. Comparison of horizontal coma of anterior corneal surface at different time points and the change values in two groups ($\bar{x}\pm s$)

Items	Groups	Before surgery	After surgery			
			The 1st week	The 1st month	The 3rd month	The 6th month
Average values	SMILE group	0.00±0.15	0.14±0.30	0.14±0.32	0.16±0.38	0.08±0.21
	LASIK group	0.01±0.13	0.07±0.54	0.03±0.51	0.05±0.56	0.02±0.57
t value		0.363	-0.848	-1.367	-1.216	-0.739
P		0.359	0.199	0.087	0.113	0.231
Change values	SMILE group	-	0.11±0.18	0.12±0.19	0.13±0.23	0.09±0.17
	LASIK group	-	0.08±0.47	0.05±0.51	0.09±0.53	0.03±0.46
t value			-0.446	0.687	-0.518	-0.916
P			0.328	0.247	0.302	0.181

Table 5. Comparison of vertical coma of anterior corneal surface at different time points and the change values in two groups ($\bar{x}\pm s$)

Items	Groups	Before surgery	After surgery			
			The 1st week	The 1st month	The 3rd month	The 6th month
Average values	SMILE group	-0.05±0.17	-0.31±0.20	-0.29±0.22	-0.29±0.21	-0.29±0.23
	LASIK group	-0.02±0.31	-0.15±0.57	-0.23±0.58	-0.25±0.61	-0.20±0.56
t value		1.482	1.982	0.724	0.464	1.112
P		0.071	0.025	0.235	0.322	0.134
Change values	SMILE group	-	-0.18±0.17	-0.21±0.20	-0.22±0.21	-0.21±0.22
	LASIK group	-	-0.13±0.51	-0.20±0.59	0.24±0.61	-0.19±0.51
t values			0.696	0.120	-0.232	0.269
P			0.244	0.452	0.408	0.394

before and after surgery in SMILE group were significantly lower than those in LASIK group (P<0.05; **Table 2**).

Comparison of spherical aberrations and the change values before and after surgery in two groups

As shown in **Table 3**, postoperative spherical aberrations at different time points in both groups were significantly increased when compared with preoperative data, and the differences were statistically significant (P<0.05). Postoperative spherical aberrations at different time points and the change values before and after surgery in SMILE group were significantly lower than those in LASIK group (P<0.05; **Table 3**).

Comparison of horizontal coma and the change values before and after surgery in two groups

As shown in **Table 4**, postoperative horizontal coma of anterior corneal surface at different time points in SMILE group was increased (P<0.05) while there was no significant change in horizontal coma in LASIK group when compared with preoperative data (P>0.05). There was no significant difference in postoperative horizontal coma at different time points and the change values before and after surgery in the two groups (P>0.05; **Table 4**).

Comparison of vertical coma and the change values before and after surgery in two groups

As shown in **Table 5**, postoperative vertical coma of anterior corneal surface at different time points in the two groups was decreased when compared with preoperative data (P< 0.05). At the postoperative 1st week, the vertical coma in SMILE group was significantly lower than that in LZSIK group (P<0.05). There was no statistically difference in change values of vertical coma before and after surgery at different time points (P>0.05; **Table 5**).

Discussion

Femtosecond laser focuses on the target tissue in the cornea with the set depth via the use of near-infrared light in pulse shapes, and then

a plasma blast occurs, thus generating tiny bubbles composted of carbon dioxide and water, which closely links together so as to achieve the precise effect of cutting tissue, so a corneal flap is made. The corneal flap made in this way has the advantages of high quality, small secondary injury, and low risk to surgery, which has been widely accepted in clinic at present [2, 6, 7]. Femtosecond laser is applied earlier to assisting LASIK surgery for making corneal flaps and lamellar keratoplasty [8], and then to assisting femtosecond lenticuleextractitm (FLEx) [9]. Small incision lenticule extraction (SMILE) is a minimally invasive refractive surgical approach with the basis of FLEx, and has a good effect on moderate to high myopia [10]. This approach can obtain stromal lenticule by femtosecond laser, which can be removed manually, as well as has the strengths of shorter operative time, small injury and good maintenance of the corneal biomechanical stability [11]. However, the problems related postoperative visual acuity still occur in some patients, such as low visual acuity at night, halo, glare disability, monocular diplopia. It is reported that the increase in postoperative high-order aberrations is the main reason for the decrease of visual quality after surgery [12].

The results of the study showed that total higher-order aberrations and spherical aberrations at postoperative 1st week, 1st month, 3rd month and 6th month in LASIK group and SMILE group were significantly increased when compared with preoperative data ($P<0.05$); at each time point after operation, total higher-order aberrations, spherical aberrations and their change values between preoperative and postoperative data in SMILE group were significant lower than those in LASIK group, and the differences were statistically significant ($P<0.05$). This might because, on the one hand, SMILE, as a new minimally invasive surgery, can effectively avoid the higher-order aberrations resulting from a wide range of surgical incision and the energy loss due to the removal of lenticule rather than excimer cutting; on the other hand, there was no need for SMILE to make corneal flap, and the lateral incision on the cornea was small, so the changes in high-order aberrations due to the incision healing via postoperative corneal epithelial hyperplasia were reduced.

Moreover, postoperative horizontal coma of anterior corneal surface at each time point in SMILE group was obviously increased ($P<0.05$) while there was no significant change in horizontal coma in LASIK group ($P>0.05$) when compared with postoperative data. Postoperative vertical coma of anterior corneal surface at each time point in both groups was significantly decreased when compared with preoperative data ($P<0.05$). Pairwise comparisons showed that there was no significant difference in postoperative horizontal coma at different time points and the change values before after surgery in the two groups ($P>0.05$). At postoperative 1st week, the negative value of vertical coma in SMILE group was significantly higher than that in LASIK group, but there was no significant difference in vertical coma of the two groups at postoperative other time points.

In summary, the two approaches each had their own particularity. Changes in postoperative higher-order aberrations of patient undergoing LASIK surgery were significantly greater than those in SMILE surgery; especially, the changes in spherical aberration were most significant, which advised surgeons that the combination of LASIK with Q value-guided or aberration-guided excimer laser cutting process was a good choice to reduce the adverse effects on spherical aberrations. When compared with the LASIK surgery, vertical coma in SMILE was significant increased, which was correlated with surgical incision location, so precise positioning for the incision could reduce the impact on coma during the surgery. Due to the single center and small sample for this study, the results have some limitations, so multi-center studies with large sample are needed in the future.

Acknowledgements

We are grateful to all the participants during performing this study.

Disclosure of conflict of interest

None.

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