ORIGINAL ARTICLE

Comparison of High Order Aberrations between Laser In Situ Keratomileusis (LASIK) and Refractive Lenticule Extraction (ReLEx) Surgery

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ABSTRACT

Background: The needs of refractive surgery with laser to correct refractive error (myopia, hyperopia, and astigmatism) have become more demanded. Eventhough the procedures can produce expected efficacy and safety, modification in corneal surface can affect optical and visual quality, resulting in visual distortion and artefacts (glare, halo, starburst) called high order aberrations (HOA).
Objective: To report the differences of high order aberration before and after corneal ablation and refractive lenticule extraction surgery.
Methods: This is an analytical retrospective observational study which conclude 60 patients (115 eyes) who underwent laser in situ keratomileusis (LASIK), femtosecond laser-assissted laser in situ keratomileusis (FS-LASIK), femtosecond lenticule extraction (FLEx), and small-incision lenticule extraction (SMILE) during the periode of January 2017 to August 2018.
Results: Of 115 eyes, the mean of pre-operative high-order abberations were divided into four groups: LASIK was 7.27±3.85, FS-LASIK was 7.06±5.77, FLEx was 6.43±3.14, and SMILE was 3.73±1.41. Trefoil was the most common high-order abberations in pre-operative data of LASIK, FLEx, and SMILE (50.0%, 56.25%, and 51.72% respectively), while coma was mostly found in FS-LASIK (46.67%). Coma was the most common finding in first and third month after surgery. High-order aberrations between first and third month after surgery were not statistically significant different (p=0.465, p=0.889, p=0.263, and p=0.508 respectively).
Conclusion: All types of procedures of corneal ablation and refractive lenticule extractions surgeries are effective and safe in correcting refractive errors. There were no differences of post-operative high- order aberrations in all types of procedures.

Keywords : *laser in situ keratomileusis, femtosecond laser-assissted laser in situ keratomileusis, refractive lenticule extraction, high order aberration, wavefront aberrometry, Zernike polynomial*

Along with advancement of technology in modern era, corneal laser refractive surgery has become tremendously favored, in purpose to eliminate refractive error or low order aberrations (myopia, hyperopia, and astigmatism). Laser in situ kerato- mileusis (LASIK) had been the preferred surgical option and was performed more than 35 millions procedures worldwide by 2010; while femosecond laser-assisted laser in situ keratomileusis (FS-LASIK), which was introduced in 2001, has been accepted well as alternative procedure due to its accuracy, safety, and predictability. The latest procedure known is refractive lenticule extraction (ReLEx), which has two form of methods: femtosecond lenticule extraction (FLEx) and small-incision lenticule extraction (SMILE). Eventhough all of these procedures are proved to be safe and can produce satisfactory results, surgical modification in cornea could affect optical quality, thus produce aberration which can cause distorsion and visual artefacts (high order aberrations).[1-7]

High order aberrations (HOAs) occurs due to ablation process in cornea, such as corneal decentration or dehydration. Total aberrations in the eye include corneal and internal aberrations. Corneal anterior surface has important role in HOAs. Changes in corneal surface's HOAs could be used to evaluat optical quality after refractive surgery. The main contributing aberrations are coma, spherical aberration, and trefoil, which are known to produce visual artefacts, such as glare, starburst, and halo. Even- though surgical result can achieve visual acuity of 20/20, patients may experience glare or discomfort.[6,8] The aim of this study is to report the comparison of HOAs before and after corneal ablation and refractive lenticule extraction surgeries.

METHODS

Subjects

This is an analytical retrospective obser- vational study which included the data from patients' medical records who under- went refractive surgeries in LASIK Unit, National Eye Center, Cicendo National Eye Hospital, Bandung, during periode of January 2017 to August 2018.

Inclusion criterion were patients who underwent HOA examination using wave-front aberrometry (iDesign® Advanced Wavescan Studio, AMO, California, USA) before surgery, 1 month, and 3 months after surgery. Exclusion criterion were patients who did not undergo HOAs examination before or in 1 and/or 3 months follow ups after surgery, also patients who had refractive media disorders.

Demographic data included age, gender, visual acuity, degree of refractive error, surgical procedure, and pre- and post-surgical HOAs.

Uncorrected visual acuity (UCVA) and best-corrected visual acuity (BCVA) were obtained using Snellen chart. Degree of refractive error was obtained from spherical equivalent (SE) and degree of astigmatism, then it was divided into three groups:

1. low (SE -1.00 – -2.75 D; cylinder < -1.75 D;
2. moderate (SE -3.00 – -6.00 D; cylinder -1.75 – -3.00 D); and
3. severe (SE ≥6.00 D; cylinder >-3.00 D)

Surgical Procedure

All of surgical procedures were performed under topical anesthesia using 2 drops of tetracaine hydrochloride 2% eye drop (Cendo Pantocain 2%). Speculum was used to keep the eyelids widely open. Surgical procedures were performed by

eight professional experienced refractive surgenos (SH, BU, MR, AW, AH, ET, ES, AFS).

Laser in situ Keratomileusis
Microkeratome (Amadeus, AMO) was used to 120-140 μm flap and hinge in 0º (nasal side). Corneal flap was lifted up with spatula to expose stromal layer. Visx STAR S4 IR® excimer laser (AMO) was used for ablating the dehydrated stromal layer. Optical zone was 6.00 mm and ablation zone was 8.00 mm. This procedure was performed with help of iris registration system on the machine. Stromal thickness was ablated up to 11-12 μm for each 1 D. Corneal flap was then repositioned using spatula. Irigation was done under the flap and in corneal surface with basal saline solution.

Femtosecond Laser-assisted LASIK
A 110 μm flap was created with laser using VisuMax femtosecond laser system (Carl Zeiss Meditec AG, Germany), with hinge in 90º (superior side). Stroma was ablated 11-12 μm for each 1 D, using the same machine for LASIK. After stromal ablation, the next steps were similar to LASIK.

Femtosecond Lenticule Extraction
Procedure was performed using VisuMax femtosecond laser system (Carl Zeiss Meditec AG, Germany). Laser was shot in three steps: (1) in posterior surface of the lenticule; (2) vertical margin; and (3) in anterior surface of the lenticule. After creating the lenticule (14-15 μm thick for each 1 D), laser was shot to create 120 μm flap and hinge in 90º (superior). Lenticule was removed and extracted from stroma using spatula. Flap was repositioned again, like was done in two previous procedures.

Small-incision Lenticule Extraction
Machine and adjusted total energy, mean shots repetition, inter-spots distance were similar to FS-LASIK. Femtosecond laser was shot in four steps:
1. posterior surface of lenticule;
2. vertical margin;
3. anterior surface of lenticule; and
4. 3.00 – 4.00 mm circumferential incision in 125º. Cut thickness and lenticule extraction procedure were similar to FLEx, but without flap creation in SMILE

Statistical Analytic

Data was recorded and processed using Microsoft® Excel and Word, while statistical analytic was processed using Statistical Package for the Social Sciences (SPSS) version 22.0 (IBM Corporation, USA) to compare pre- and post-surgery HOAs using Wilcoxon test, with $p<0.05$ statistically significant.

RESULTS

During period of January 2017 to August 2018, there were 695 patients (1,330 eyes) underwent refractive surgery in our LASIK Unit; but only 60 patients (115 eyes) met the inclusion criterion.

Demographic data (Tabel 1) showed that 56.7% of patients were male, with mean age of 21.5±5.4 years (18 – 44 years), mostly under 20 years (55.0%). Initial UCVA was found mostly in 0.02 – 0.08 (50.4%), with degree of refractive error was in moderate group (39.1%). We found 40 (34.78%) eyes underwent LASIK. In the first month follow-up after surgery, of all the procedures, 71.3% of eyes had UCVA similar to pre-operative BCVA; while in third month after surgery, 53.0% of eyes had UCVA similar to pre-operative BCVA. Unfortunately, 31 (27.0%) of eyes were lost follow-up in third month. The distribution of post-operative visual acuity could be seen in Fig 1.

Pre-operative and 1 month post-operative HOAs changes were statistically significant, while HOAs changes in third and first month post-operative were not

statistically significant in LASIK, FS-LASIK, FLEx, and SMILE (p=0.465, p=0.889, p=0.263, and p=0.508, respectively).

Trefoil was found to be frequent in pre-operative examination in LASIK (50.0%), FLEx (56.25%), and SMILE (46.67%); while coma was frequent in FS-LASIK group (51.72%). One month after surgery, coma was frequently found after each procedure (LASIK 27.5%, FS-LASIK 20.69%, FLEx 18.75%, and SMILE 26.67%); trefoil was also frequently found after LASIK (20.69%) and FLEx (18.75%). Three month after surgery, coma was mostly found in all procedures.

There was no any intraoperative complication in each surgical procedure.

DISCUSSION

High order aberrations (HOAs) is a part of refractive error and has been an important component in optic and visual science. High order aberrations is a light wave distortion when passing through tear film and irregular refractive media. Unlike low order aberrations (LOAs), HOAs could not be corrected with spectacles or contact lens. Eventhough refractive surgery could eliminate refractive errors, patients may often complain about halo, glare, starburst, and even decreased contrast sensitivity. They are the main factors affecting post-operative optical quality in patients.[8-14]

Geometrical aberrations are described mathematically using Zernike polynomial. The HOAs start form level three of Zernike. Coma (Z_{3-1}, Z_{31}, Z_{5-1}, and Z_{51}), trefoil (Z_{3-3}, Z_{33}, Z_{5-5}, and Z_{55}), and spherical aberration or SA (Z_{40} and Z_{60}) are the important HOAs.

Relationship between HOAS and refractive error has been investigated in many studies but the results were remain in controversy.[10,14-17]

In this study, all of four procedures produce efficacy and safety in correcting refractive error. Post-operative UCVA achieved 1.0 (similar to pre-operative BCVA) and better than pre-operative BCVA in the first month were 71.3% and 15.7%, respectively; and were 72.6% and 20.2%, respectively, in the third month These findings were in concordance with studies by Liu et al, Al-Zeraid et al, and Sekundo et al.[3,4,18]

Table 1. Patients characteristics (n=60, 115 eyes)

Characteristics	Total	%
Gender		
Male	34	56.7
Female	26	43.3
Age		
<20	33	55.0
20-29	21	35.0
≥30	6	10.0
Mean±SD	21.5±5.4	
Range	18-44	
Laterality of operated eye(s)		
Bilateral	56	93.3
Unilateral	4	6.7
UCVA		
0.5-0.8	7	6.1
0.32-0.4	17	14.8
0.1-0.25	33	28.7
0.02-0.08	58	50.4
Degree of refractive error		
Low	44	38.8
Moderate	45	39.1
High	26	22.6
Surgical Procedure		
LASIK	40	34.8
FS-LASIK	29	25.2
FLEx	16	13.9
SMILE	30	26.1

FLEx: femtosecond lenticule extraction; **FS-LASIK**: femto- second laser-assissted laser in situ keratomileusis; **LASIK**: laser in situ keratomileusis; **SD**: standard deviation; **SMILE**: small incision lenticule extraction; **UCVA**: uncorrected visual acuity.

Table 2. Pre and post-operative HOAx changes

	Pre-operative (%)	First month after surgery (%)	*p**	Third month after surgery (%)	*p**
LASIK	7,27±3,85	33,11±17,86	0,000	29,02±16,86	0,465
FS-LASIK	6,73±5,15	29,85±21,78	0,000	26,23±16,87	0,889
FLEx	5,18±2,86	34,83±21,72	0,008	31,24±22,16	0.263
SMILE	4,23±2,65	31,82±10,44	0,000	27,68±17,12	0,508

p value using Wilcoxon test.
FLEx: femtosecond lenticule extraction; **FS-LASIK**: femto-second laser-assissted laser in situ keratomileusis; **LASIK**: laser in situ keratomileusis; **SMILE**: small incision lenticule extraction.

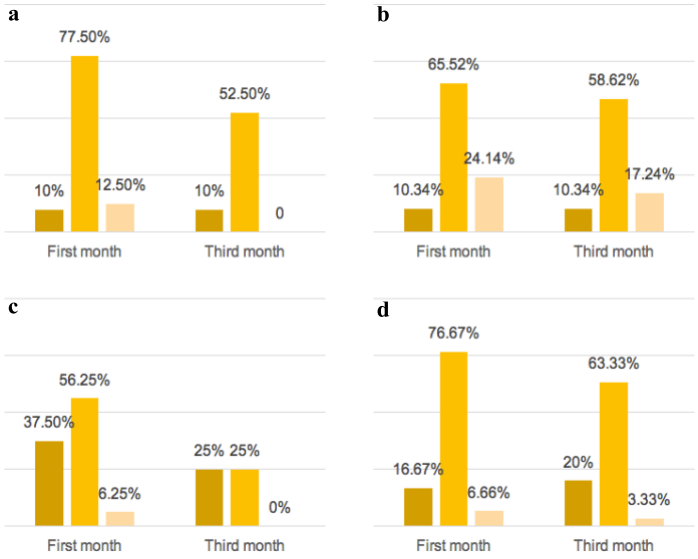

Fig 1. Comparison of pre-operative best-corrected visual acuity (BCVA) and post-operative uncorrected visual acuity (UCVA) in each surgical procedure: **(a)** laser in situ keratomileusis (**LASIK**); **(b)** femtosecond laser-assissted laser in situ keratomileusis (**FS-LASIK**); (**c**) femtosecond lenticule extraction (**FLEx**); and (**d**) small-incision lenticule extraction (**SMILE**).

Coma and SA are commonly found in normal population and some studies reported that both of these type of HOAs could occur after refractive surgery. Coma can result in monocular diplopia and comet-tail star-burst; while SA causes starburst and glare. Mirjazani et al and Jesson et al reported that spherical aberration and coma were commonly found; but in our study, trefoil was found to be common in pre-operative examination in LASIK, FLEx, and SMILE, and coma was common in FS-LASIK. The difference of HOA could be affected by ethnic factor. Prakash et al reported Asia (Chinese) ethnic tended to have HOAs order four or lower and India or white ethnic who have HOA order five or higher.[17,19-21]

Al-Zeraid et al reported that HOAs after LASIK was induced by following factors: variation in HOAs measurements due to fluctuative accomodation and tear film; incorrect measurement and eye mis-alignment during surgery (cyclotorsion); and velocity of excimer laser shots. Agca et al and Yildirim et al reported that total corneal HOA significantly increased after LASIK, FLEx, and SMILE (especially coma, trefoil, and SA). Liu et al reported that SMILE induced lower amount of SA compared to FS-LASIK in sixth month after surgery; while Ye et al reported there was no difference in corneal HOAs changes between LASIK and FS-LASIK. In this study, coma was the common HOA found in each procedure in first and third month after surgery.[3,4-6,21,22]

Table 3. Tipe HOA pre-operatif dan post-operatif berdasarkan polinomial Zernike

	LASIK (n=40)	FS-LASIK (n=29)	FLEx (n=16)	SMILE (n=30)
Pre-operative				
Coma	14 (35.0%)	15 (51.72%)	6 (37.5%)	9 (30.0%)
Trefoil	20 (50.0%)	12 (41.38%)	9 (56.25%)	14 (46.67%)
Tetrafoil	1 (2.5%)	1 (3.45%)	0 (0.0%)	0 (0.0%)
SA	3 (7.5%)	0 (0.0%)	1 (6.25%)	6 (20.0%)
2nd order astigmatism	2 (5.0%)	1 (3.45%)	0 (0.0%)	1 (3.33%)
First month post-operative				
Coma	11 (27.5%)	6 (20.69%)	3 (18.75%)	8 (26.67%)
Trefoil	7 (17.5%)	6 (20.69%)	3 (18.75%)	3 (10.0%)
Tetrafoil	1 (2.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
SA	2 (5.0%)	0 (0.0%)	1 (6.25%)	0 (0.0%)
2nd order astigmatism	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
N/A	19 (47.5%)	17 (58.62%)	9 (56.25%)	19 (63.33%)
Third month post-operative				
Coma	13 (32.5%)	5 (17.24%)	3 (18.75%)	13 (43.33%)
Trefoil	2 (5.0%)	1 (3.45%)	3 (18.75%)	3 (10.0%)
Tetrafoil	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
SA	1 (2.5%)	0 (0.0%)	0 (0.0%)	2 (6.67%)
2nd order astigmatism	0 (0.0%)	1 (3.45%)	0 (0.0%)	0 (0.0%)
N/A	25 (62.5%)	22 (75.86%)	10 (62.5%)	12 (40.0%)

FLEx: femtosecond lenticule extraction; **FS-LASIK**: femto-second laser-assissted laser in situ keratomileusis; **LASIK**: laser in situ keratomileusis; **SA:** spherical aberration; **SMILE**: small incision lenticule extraction; **N/A**: not available

The limitations of this study are: (1) retrospective study, which probability of information bias is high; (2) inhomogenous samples; (3) not all of the patients did consecutive post-surgical visit in first or third month; (4) incomplete post-surgical examination data of HOAs in medical records or *wavefront aberrometry* machine; and (5) relationship of post-surgical dry eyes and HOAs was not considered.

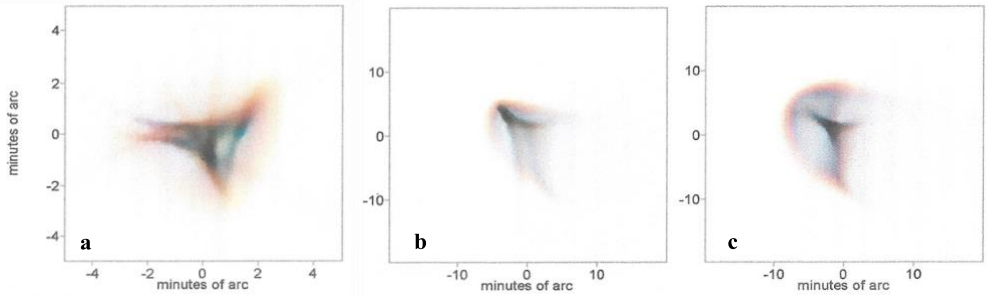

Fig 2. An example of manifestation of HOAs based on point spread function (PFS), taken from iDesign® Advanced Wavescan Studio on the same patient and the same eye. **a)** pre-operative examination showed starburst caused by spherical aberration (SA); **b)** first month and **c)** third month after surgery showed that SA changed to coma (comet). Higher amount of coma in third month

CONCLUSION

Corneal ablation and refractive lenticule extraction surgeries are the safe and effective procedures to eliminate refractive error. There is no significant differences of HOAs changes in LASIK, FS-LASIK, and SMILE in first and third month after surgery. Undersatnding HOAs could help us, as refractive surgeon, to provide the patients the information about the possibility of

imperfect optical quality and discomfort eventhough their visual acuity could reach 1.0 or 20/20. Further study with larger and homogenous samples is needed.

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