COMPARISON OF VISUAL ACUITY AND HIGHER-ORDER ABERRATIONS AFTER STANDARD AND WAVEFRONT-GUIDED MYOPIC FEMTOSECOND LASIK

Anderle R.[1,2], Ventruba J.[1], Skorkovská Š.[1,3]

[1] European Eye Clinic LEXUM, Brno, Head doc. MUDr. Šárka Skorkovská, CSc.
[2] Department of Biophysics, Faculty of Medicine, Masaryk University Brno, Head prof. RNDr. Vojtěch Mornstein, CSc.
[3] Ocular Disorders and Optometry Clinic of St. Anna University Hospital, Brno , Head doc. MUDr. Svatopluk Synek, CSc.

Mgr. R. Anderle
Evropská oční klinika LEXUM
Bezručova 22
603 00 Brno
e-mail: anderle@lexum.cz

SUMMARY

Purpose: To analyze and compare visual acuity, refractive outcomes and higher-order aberrations after standard and wavefront-guided Femto-LASIK at 1, 3, and 12 months postoperatively.

Methods: Study of 95 consecutive eyes of myopic patients (-0.5 to -7.0 D), who underwent Femto-LASIK with standard ablation profile (STA) (49 eyes) or wavefront-guided ablation (WFG) (46 eyes) using femtosecond laser LDV Ziemer and excimer laser MEL 80 Zeiss with iris registration. Primary outcome measures were uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), manifest refraction and higher-order ocular aberrations (HOAs). HOAs were measured with Hartmann-Shack wavefront aberrometer WASCA, HOAs analyzed at 6 mm pupil, assessed total HOAs root mean square (RMS HOAs) and individual Zernike coefficients.

Results: Preoperatively, there were no significant differences between STA and WFG groups in UDVA, CDVA, manifest refraction or HOAs. As compared with preoperative values, spherical aberration Z(4,0) increased by 0.24 µm in both groups and it is the main increasing factor of RMS HOAs (0.05 µm in STA group and 0.08 µm in WFG group). Safety and efficacy index is 1.0 in both ablation profiles. Postoperatively, median UDVA and CDVA achieved 1.2. No patient lost line of CDVA at 12 month postoperatively. All patients were within ± 0,5 D of emmetropia at 12 months. Significant differences were not found between STA and WFG in UDVA, CDVA, manifest refraction or HOAs at 1, 3 and 12 month.

Conclusions: Both wavefront-guided and standard Femto-LASIK with LDV and MEL 80 platform have shown very good efficacy and safety. Myopic Femto-LASIK only slightly increases RMS HOAs, especially by induction of spherical aberration. Both methods have equivalent postoperative aberration score one year postoperatively.

Key words: femtosecond LASIK, higher-order aberrations, wavefront-guided, visual accuity.

Čes. a slov. Oftal., 71, 2015, No. 1, p. 44–50

INTRODUCTION

A range of studies have demonstrated good results of LASIK operations, within a regime of both standard and individualised, "customised" ablations. At present the most commonly performed ablations are standard (removal of spherical and cylindrical element of refractive error), wavefront-optimized (with correction of spherical ablation) and wavefront-guided ablations (with correction of higher order aberrations). Some studies state an advantage of wavefront-guided ablations in comparison with standard ablations in the sense of lower induction of higher order aberrations. Some authors state that wavefront-guided ablations are suitable only for patients with higher preoperative values of higher order operations, and on the contrary are not beneficial for patients with lower values of preoperative aberrations (12, 19). In our study we evaluated visual acuity and higher order aberrations in myopic eyes before and after a Femto-LASIK laser refractive operation, with the use of standard or wavefront-guided ablation.

METHOD

A retrospective study evaluated data from Femto-LASIK primary laser refractive surgery, with the use of an LDV Z6 (Ziemer) femtosecond laser and MEL 80 (Carl Zeiss Meditec) excimer laser with iris registration. All the parameters were measured by the same person (R.A.) and all operations were performed by a single surgeon (J.V.) at the LEXUM (Optegra) European Eye Clinic in Brno. Patients with myopia with or without astigmatism were included in the study. All eyes were corrected for distance vision in emmetropia.

The preoperative examination covered measurement of manifest and cycloplegic refraction, uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), tonometry, aberrometry, corneal analysis (Pentacam Oculus), examination on slit lamp (anterior segment and posterior segment in artificial mydriasis), evaluation of lacrimal film.

Visual acuity was tested on a Tomey TCP-2000P LCD optotype at a distance of 5.2 metres. Vision was recorded by the interpolation method. Objective refraction was measured on a Nidek ARK-510A autorefractometer under photopic conditions. Total ocular aberrations of the higher orders (HOAs – higher order aberrations) were measured on a WASCA Analyser instrument under scotopic conditions and analysed for a pupil diameter of 6 mm. This instrument is based on the principle of a Shack-Hartmann sensor, the source of the measuring ray is a superluminescent diode with a wavelength of 835 nm. Zernike polynomials were used for interpretation of higher order aberrations, HOAs were analysed to the fourth row (Z4).

The observed parameters of **UDVA, CDVA, spherical de-**

fect, cylindrical defect and HOAs were measured before surgery, and 1, 3 and 12 months after surgery.

In the refractive procedure, an LDV Z6 (Ziemer) femtosecond laser was used for the creation of lamellas, the thickness of the lamellas was from 90 to 140 µm, size from 8.5 to 10.0 mm. A MEL 80 (Carl Zeiss, Meditec) excimer laser was used for the removal of refractive errors, the width of the optic ablation zone was 6.5 mm, the ablation profile was either "Standard SCA" (removal of spherical and cylindrical element of refractive error), or "Wavefront ablation" (with additional correction of higher order aberrations up to the fourth row), always within a regime of an active eye tracker with iris registration.

A statistical analysis was conducted using the program Statistica 12 (StatSoft). For the analysis of visual acuity, a median with quantiles and Mann-Whitney U test were used, for manifest refraction and higher order aberrations the average with a standard deviation and t-test was used. We stipulated the level of statistical significance at $p < 0.05$.

RESULTS

The study included a total of 95 eyes. In the group of **standard ablation (STA)** there were 49 eyes, average age 31.8 ± 9.2 years (range from 19 to 56 years), the refractive spherical error was on average -3.4 ± 1.8 Dsf (range -0.5 to -7.0), cylindrical error -0.8 ± 0.6 Dcyl (range 0 to -2.75). In the group of **wavefront-guided ablation (WFG)** there were 46 eyes, average age 31.9 ± 6.7 years (range 22 to 48 years), refractive spherical error was on average -3.6 ± 1.3 Dsf (range -1.5 to – 6.25), cylindrical error -0.7 ± 0.6 Dcyl (range 0 to -2.0).

Visual acuity

Following the laser refractive procedure, median **UDVA and CDVA was 1.2**, both in the group of STA (table 1, 3, graph 1, 2) and in the group of WFG (table 2, 4, graph 1, 2) at all postoperative follow up examinations 1, 3 and 12 months after surgery. The **safety index** (postoperative CDVA / preoperative CDVA) reached a value of 1.0. Loss of a row did not occur in any patient after 12 months. The **efficacy index** (postoperative UDVA / preoperative UDVA) reached a value of 1.0. No statistically significant difference in visual acuity was determined between standard and wavefront-guided ablation.

Manifest refraction

Postoperative subjective refraction in both groups is shown by tables 5 and 6, and by graphs 3 and 4. **All patients** had **less than ± 0.5 D** 12 months after surgery. Laser enhancement was not performed on any patient during the course of the study. No statistically significant difference was found in manifest refraction between standard and wavefront-guided ablation

Wavefront analysis and higher order aberration

Root Mean Square Higher-Order Aberrations (RMS HOAs) – the mean quadratic average of higher order aberrations increased slightly postoperatively in both groups from 0.27 ± 0.09 µm to 0.32 ± 0.10 µm (STA) and from 0.26 ± 0.09 µm to 0.34 ± 0.13 µm (WFG). **No statistically significant difference between standard and wavefront-guided ablation was determined in the RMS HOAs** (table 7, graph 5).

The results of the individual higher order aberrations are presented by table 8 and graphs 6-9.

The myopic ablation profile indicates spherical ablation Z (4.0) in the case of STA and WFG ($p < 0.001$). In both profiles there is an identical increase by 0.24 µm in a comparison of the preoperative values and the values 12 months after surgery. In addition there is a slight increase of coma in both STA and WFG Z (3.1), Z (3.-1) ($p < 0.01$). None of the other aberrations differ statistically significantly in time.

No statistically significant differences between the values of the individual higher order aberrations following standard and wavefront-guided ablation were determined 1, 3 and 12 months after surgery.

DISCUSSION

The main aim of our study was to evaluate and compare the results of standard and wavefront-guided ablations in Femto-LASIK operations. One of the most important magnitudes for determining visual functions is visual acuity. This study demonstrated excellent and stable results after one year upon the use of both STA and WFG ablation, as well as the safety and efficacy of the Femto-LASIK method. Loss of an optotype row following the refractive procedure did not occur in any patient. At the same time, the effectiveness of the laser procedure was confirmed (5, 11). Patients had the same or better uncorrected visual acuity following surgery in comparison with best corrected visual acuity before the procedure. The residual refractive error was within a range of less than ±0.5D.

Various laser platforms and ablation profiles indicate higher order aberrations to a varying degree (10, 20, 22). In our case, RMS HOAs was very similar in both groups. We did

Tab. 1

	Uncorrected distance visual acuity UDVA – Standard ablation				
	Median	Minimum	Maximum	10th quantile	90th quantile
Preoperative	**0.08**	0.01	0.70	0.01	0.25
1m	**1.20**	0.80	1.60	0.95	1.30
3m	**1.20**	0.90	1.60	1.00	1.30
12m	**1.20**	0.95	1.50	1.00	1.30

Tab. 2

	Uncorrected distance visual acuity UDVA – Wavefront-guided ablation				
	Median	Minimum	Maximum	10th quantile	90th quantile
Preoperative	**0.05**	0.01	0.20	0.05	0.16
1m	**1.20**	0.80	1.50	0.95	1.40
3m	**1.20**	0.90	1.70	1.00	1.50
12m	**1.20**	0.80	1.60	0.95	1.50

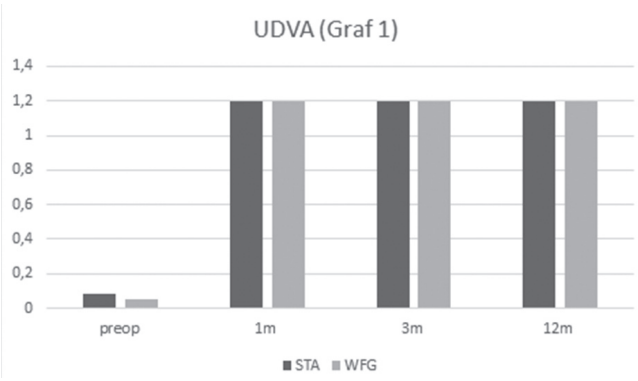
Tab. 3

	Corrected distance visual acuity CDVA – Standard ablation				
	Median	Minimum	Maximum	10th quantile	90th quantile
Preoperative	**0.05**	0.80	1.50	0.95	1.40
1m	**1.20**	0.80	1.60	1.00	1.40
3m	**1.20**	0.90	1.60	1.00	1.45
12m	**1.20**	0.95	1.50	1.10	1.30

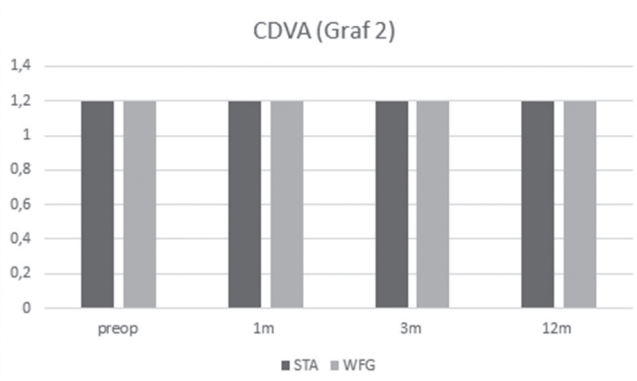
Tab. 4

	Corrected distance visual acuity CDVA – Wavefront-guided ablation				
	Median	Minimum	Maximum	10th quantile	90th quantile
Preoperative	**1.20**	0.90	1.50	1.00	1.45
1m	**1.20**	0.80	1.50	1.00	1.45
3m	**1.20**	0.90	1.70	1.00	1.50
12m	**1.20**	0.90	1.60	1.00	1.50

not find any difference in this parameter. A comparison of the individual aberrations between STA and WFG ablation demonstrated that the use of WFG in lower values of HOAs does not have a fundamental influence on the result of the procedure (see table 7, graph 5). Similar results were found in the study conducted by Yu et al., who compared the one-year values of HOAs upon the use of two types of excimer lasers (Allegretto Wave Eye-Q and Visx Star CustomVue S4 IR) (21). The initial preoperative values were very similar to our values. Upon the use of these lasers, postoperative RMS HOAs in their case was 0.33 µm and 0.40 µm. In our case the one-year results of RM HOAs were 0.32 µm for STA ablation and 0.34 µm for WFG ablation. Similar results were also attained by the authors Perez-Straziota et al., who compared wavefront-guided ablation (Visx Star S4) and wavefront-optimized ablation (WaveLight Allegretto Wave). Here also they found no statistically significant differences in postoperative visual acuity, residual refractive error and higher order aberrations (16). The authors Smajda et al., who compared the results of 36 studies (17), also refer to various ablation profiles. In this work they too found no statistically significant differences of higher order aberrations. Moshirfar et al. examined the influence of the thickness of corneal lamella upon LASIK on the resulting values of visual acuity,



Graph 1



Graph 2

contrast sensitivity and induction of higher order aberrations (14). Here also, no significant differences were ascertained. The study by the authors Tomita et al, focusing on the results of 10 235 myopic eyes operated on by the LASIK method on a Schwind Amaris platform demonstrated that induction of higher order aberrations occurred even despite the use of wavefront-optimized ablation (18). The study by the authors Majida et al. amongst other factors compares the results of higher order aberrations on the platform of an IntraLase femtosecond laser and Visx Star S4 upon the use of wavefront-guided ablation (13). The initial value of RMS HOAs in their case was 0.34 µm, preoperative refractive error on average -4.27 D. At a follow-up examination after 6 months they measured average RMS HOAs of 0.59 µm. Induction of higher order aberrations on this platform was therefore 0.25 µm. In our case, induction of RMS HOAs was only 0.08 µm. Even though the initial values of preoperative manifest refraction were fractionally higher (by 0.38 D) than in our study cohort, it ensues from the comparison that the platform LDV Z6 + MEL 80 induces preoperatively fundamentally less higher order aberrations.

The measured values of higher order aberrations are influenced by several factors, such as correct fixation of the examined eye, size of pupil, age, accommodation, quality of lacrimal film etc. Each higher order aberration has a different influence on the quality of vision. Studies in this area demonstrate that aberrations located in the centre of Zernike pyramid of polynomials have the most fundamental significance on the quality of vision. Coma and spherical aberrations rank amongst the aberrations which have a more significant influence on the quality of vision (2). Total spherical aberration of the eye in younger individuals reaches negative values. Around the age of forty years there is a gradual transition into plus values. The value of spherical aberration increases with the diameter of the pupil, and as a result miosis at more advanced age is considered a protective phenomenon in a manifestation of primarily spherical aberration (3). At the same time it has been demonstrated that combinations of certain higher order aberrations have a more fundamental influence on quality of vision. In practice this means that we can have two patients with the same RMS HOAs value, but the one of them who has an adverse combination of HOAs will be subjectively (and objectively) burdened by negative perception of visual functions (1).

In our study, the results of the individual aberrations of the third and fourth row are as follows: In the case of trefoil

Tab. 5

	Spherical element of subjective refraction (D)				
	Standard ablation		Wavefront-guided ablation		p
	Average	/ SD	Average	/ SD	
Preoperative	**-3.44**	±1.76	**-3.55**	±1.30	**0.74**
1m	**0.11**	±0.20	**0.11**	±0.22	**0.88**
3m	**0.09**	±0.19	**0.05**	±0.22	**0.36**
12m	**-0.01**	±0.18	**0.04**	±0.24	**0.37**

Tab. 6

	Cylindrical element of subjective refraction (D)				
	Standard ablation		Wavefront-guided ablation		p
	Average	/ SD	Average	/ SD	
Preoperative	**-0.81**	±0.64	**-0.68**	±0.60	**0.31**
1m	**-0.02**	±0.11	**-0.08**	±0.21	**0.15**
3m	**-0.06**	±0.21	**-0.03**	±0.13	**0.45**
12m	**-0.03**	±0.12	**-0.07**	±0.19	**0.28**

Tab. 7

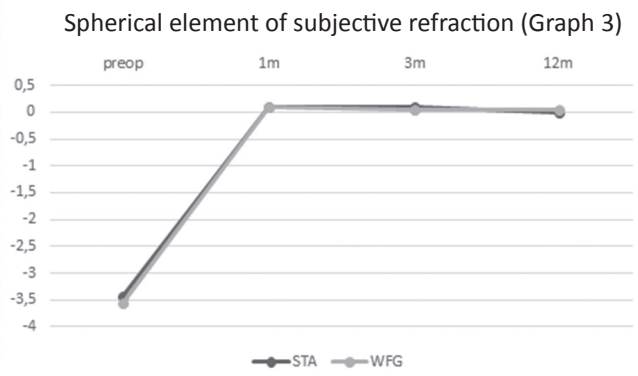
	RMS HOAs (µm)				
	Standard ablation		Wavefront-guided ablation		p
	Average	/ SD	Average	/ SD	
Preoperative	**0.27**	±0.09	**0.26**	±0.09	**0.75**
1m	**0.34**	±0.12	**0.34**	±0.12	**0.97**
3m	**0.31**	±0.12	**0.32**	±0.11	**0.84**
12m	**0.32**	±0.10	**0.34**	±0.13	**0.36**

Tab. 8

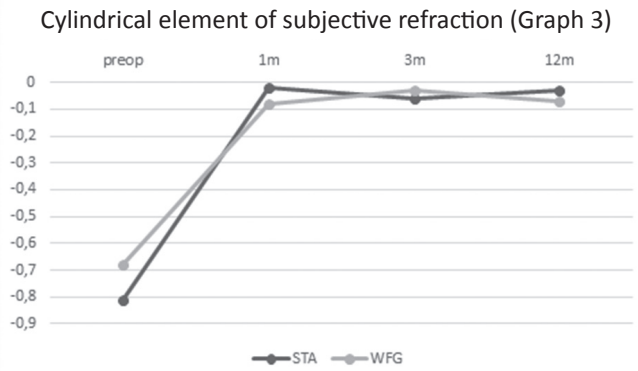
	Individual aberrations (µm)				
	STA ablation		WFG ablation		p
	Average	/ SD	Average	/ SD	
Z (3.-3) pre	**0.04**	±0.26	**0.03**	±0.23	**0.86**
Z (3.-3) 1m	**0.00**	±0.25	**0.07**	±0.21	**0.17**
Z (3.-3) 3m	**0.02**	±0.21	**0.05**	±0.21	**0.53**
Z (3.-3) 12m	**0.06**	±0.26	**0.02**	±0.21	**0.38**
Z (3.-1) pre	**0.00**	±0.32	**0.03**	±0.24	**0.66**
Z (3.-1) 1m	**-0.06**	±0.42	**-0.16**	±0.37	**0.28**
Z (3.-1) 3m	**-0.17**	±0.42	**-0.15**	±0.31	**0.69**
Z (3.-1) 12m	**-0.25**	±1.60	**-0.21**	±0.39	**0.85**
Z (3.1) pre	**0.05**	±0.43	**0.00**	±0.45	**0.53**
Z (3.1) 1m	**-0.05**	±0.43	**-0.16**	±0.50	**0.31**
Z (3.1) 3m	**-0.06**	±0.47	**-0.09**	±0.53	**0.79**
Z (3.1) 12m	**-0.14**	±0.41	**-0.10**	±0.54	**0.66**
Z (3.3) pre	**-0.09**	±0.30	**-0.08**	±0.32	**0.98**
Z (3.3) 1m	**-0.12**	±0.30	**-0.09**	±0.25	**0.69**
Z (3.3) 3m	**-0.06**	±0.32	**-0.06**	±0.25	**0.95**
Z (3.3) 12m	**-0.11**	±0.24	**-0.06**	±0.27	**0.43**
Z (4.-4) pre	**0.00**	±0.11	**-0.04**	±0.17	**0.30**
Z (4.-4) 1m	**0.01**	±0.13	**0.02**	±0.09	**0.62**
Z (4.-4) 3m	**0.03**	±0.11	**0.00**	±0.11	**0.29**
Z (4.-4) 12m	**0.00**	±0.16	**0.01**	±0.11	**0.65**
Z (4.-2) pre	**0.02**	±0.11	**0.00**	±0.11	**0.32**
Z (4.-2) 1m	**0.03**	±0.11	**0.00**	±0.15	**0.49**
Z (4.-2) 3m	**0.03**	±0.15	**0.00**	±0.15	**0.38**
Z (4.-2) 12m	**0.02**	±0.12	**-0.01**	±0.15	**0.23**
Z (4.0) pre	**0.10**	±0.27	**0.05**	±0.26	**0.42**
Z (4.0) 1m	**0.40**	±0.27	**0.32**	±0.33	**0.23**
Z (4.0) 3m	**0.33**	±0.25	**0.26**	±0.32	**0.28**
Z (4.0) 12m	**0.34**	±0.22	**0.29**	±0.35	**0.46**
Z (4.2) pre	**0.01**	±0.17	**0.07**	±0.17	**0.11**
Z (4.2) 1m	**0.07**	±0.23	**0.08**	±0.21	**0.97**
Z (4.2) 3m	**0.08**	±0.23	**0.10**	±0.18	**0.39**
Z (4.2) 12m	**0.05**	±0.18	**0.12**	±0.19	**0.10**
Z (4.4) pre	**-0.04**	±0.11	**-0.01**	±0.12	**0.30**
Z (4.4) 1m	**-0.02**	±0.13	**0.00**	±0.13	**0.44**
Z (4.4) 3m	**-0.03**	±0.11	**0.02**	±0.13	**0.11**
Z (4.4) 12m	**0.00**	±0.14	**0.01**	±0.14	**0.97**

Z(3.-3) and Z(3.3) there were no significant changes before or after surgery upon either STA or WFG ablation. In the case of coma Z(3.-1) and Z(3.1) there was a postoperative increase of this aberration in the case of both ablations, which concurs with the results of a range of studies. We did not demonstrate any statistical difference between induced coma of STA and WFG ablation. For quadrafoil Z(4.-4) and Z(4.4) and secondary astigmatism Z(4.-2) and Z(4.2) we again did not determine any difference in the values before and after surgery upon the use of both ablations. Spherical aberration Z(4.0) similarly increases both in the case of STA and WFG ablation. No statistically significant difference was found between STA and WFG ablation (see table 8).

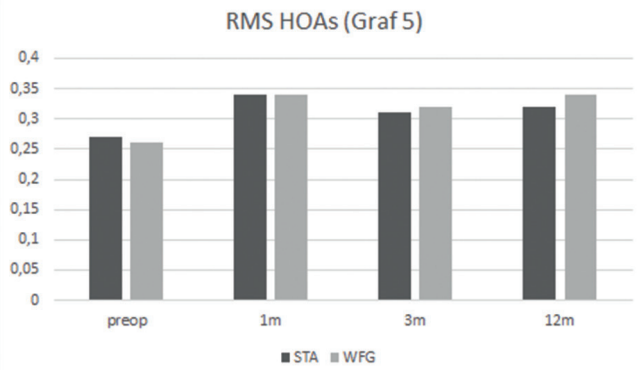
Precise centration of ablation on the axis of view has a fundamental influence on induced higher order aberrations (15). As a result, in order to ensure good results it is necessary to perform ablations with an active eye tracker, which monitors slight movements of the eye and is capable



Graph 3



Graph 4

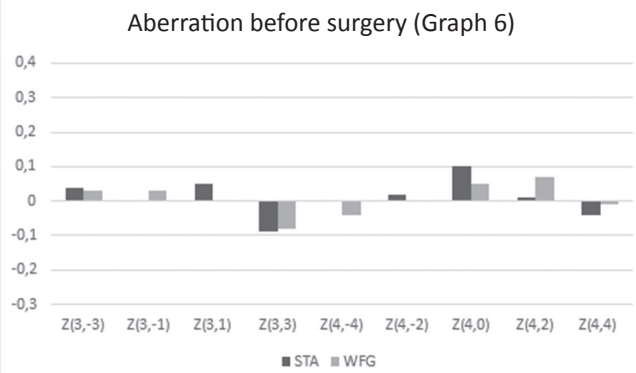


Graph 5

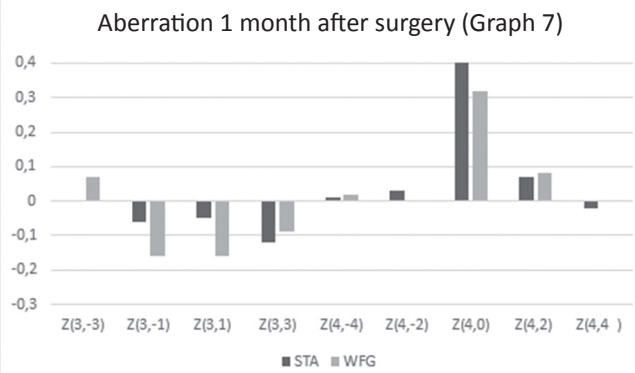
of diverting the laser beam in such a manner that it always hits the designated place on the surface of the cornea. The size of the ray of the excimer laser also has a fundamental influence on the quality of ablation upon removal of higher order aberrations. It has been demonstrated that the ray should have a maximum diameter of 1 mm for the removal of aberrations up to the fourth row, and for removal of aberrations up to the sixth row maximum 0.6 mm (8, 9). With a larger diameter the ray does not have sufficient capability of correcting more complex aberrations.

The question of whether and when it makes sense to use wavefront-guided ablation remains a decision for the indicating doctor, and it is difficult to propose a universal solution. Some studies indicate that it makes sense to perform WFG ablation upon initial values of RMS HOAs of more than 0.3 µm (6). In this decision it is necessary to combine experience with specific instrument equipment, the specific demands of the patient, personal experience with similar cases and other factors (7). In order to confirm the potential advantages of the individual ablation profiles, a contralateral eye design study would undoubtedly be more appropriate, since two eyes (corneas) of one patient respond more similarly to treatment (ablation by excimer laser) than two eyes of two different patients (4). It would also be appropriate to verify the effect of ablation profiles on a larger number of patients and stratify them into groups according to the above preoperative higher order aberrations.

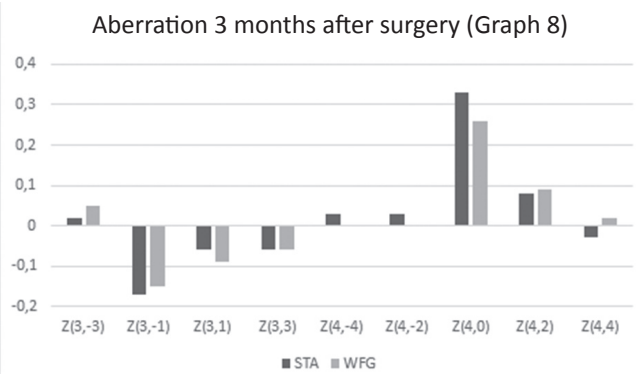
The platform of the combination of LDV Z6 + MEL 80 demonstrated excellent results, safety, efficacy, predictability and minimal induction of higher order aberrations.



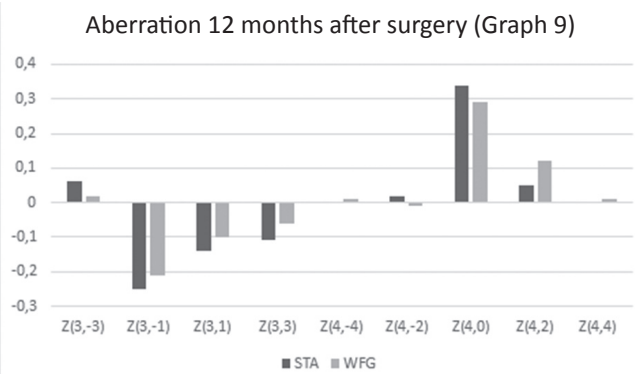
Graph 6



Graph 7



Graph 8



Graph 9

LITERATURE

1. **Applegate, R.A., Marsasck, J.D., Ramos, R. et al.:** Interaction between aberrations to improve or reduce visual performance. J Cataract Refract Surg, 2003; 29: 1487–1495.
2. **Applegate, R.A., Sarver, E.J., Khemsara, V.:** Are all aberrations equal? J Refract Surg, 2002; 18: 556–562.
3. **Artal, P., Berrio, E., Guirao, A. et al.:** Contribution of cornea and internal surfaces to the change of ocular aberrations with age. J Opt Soc Am Opt Image Sci Vis, 2002; 19: 137–143.
4. **El Danasoury, A.M., Holladay, J., Waring, G.O. 3rd, et al.:** A contralateral, randomized comparison of optimized prolate ablation and conventional LASIK for myopia with the NIDEK excimer laser platform. J Refract Surg, 2012 Jul; 28(7): 453–61.
5. **Fares, U., Suleman, H., Al-Aqaba, M.A. et al.:** Efficacy, predictability, and safety of wavefront-guided refractive laser treatment: metaanalysis. J Cataract Refract Surg, 2011; 37(8): 1465–75.
6. **Feng, Y., Yu, J., Wang, Q.:** Meta-analysis of wavefront-guided vs. wavefront-optimized LASIK for myopia. Optom Vis Sci, 2011; 88(12): 1463–1469.
7. **Franzco, M.L., Hodge, Ch.:** Wavefront´s role in corneal surgery. Clinic Experimental Ophthal, 2005; 33: 199–209.

8. **Guirao, A., Williams, D.R., MacRae, S.M.:** Effect of beam size on the expected benefit of customized laser refractive surgery. J Refract Surg, 2003; 19: 15–23.
9. **Huang, D., Arif, M.:** Spot size and quality of scanning laser correction of higher-order wavefront aberrations. J Cataract Refract Surg, 2002; 28: 407–16.
10. **Chalita, M.R., Chavala, S., Xu, M. et al.:** Wavefront analysis in post-LASIK eyes and its correlation with visual symptoms, refraction and topography. Ophthalmology, 2004; 11: 447-453.
11. **Kanellopoulos, A.J., Asimellis, G.:** Refractive and keratometric stability in high myopic LASIK with high-frequency femtosecond and excimer laser. J Refract Surg, 2013; 29(12): 832–837.
12. **Kermani, O., Schmiedt, K., Oberheide, U. et al.:** Topographic and wavefront-guided customized ablations with the NIDEK-EC5000CXII in LASIK for myopia. J Refract Surg, 2006; 22(8): 754–763.
13. **Moshirfar, M., Schliesser, J.A., Chang, J.C. et al.:** Visual outcomes after wavefront-guided photorefractive keratectomy and wavefront-guided laser in situ keratomileusis: Prospective comparison. J Cataract Refract Surg, 2010; 36: 1336–1343.
14. **Moshirfar, M., Hatch B.B., Chang J.C., et al.:** Prospective, contralateral comparison of 120-µm and 90-µm LASIK flaps using the IntraLase FS60 femtosecondlaser. J Refract Surg. 2011 Apr;27(4):251-9.
15. **Mrochen, M., Keammerer, M., Mierdel, P. et al.:** Increased higher-order aberrations after laser refractive surgery: a problem of subclinical decentration. J Cataract Refract Surg, 2001; 27: 362–369.
16. **Perez-Straziota, C.E., Randleman, J.B., Stulting, R.D.:** Visual acuity and higher-order aberrations with wavefront-guided and wavefront-optimized laser in situ keratomileusis. J Cataract Refract Surg, 2010 Mar; 36(3): 437–41.
17. **Smadja, D., Reggiani-Mello, G., Santhiago, M.R., et al.:** Wavefront ablation profiles in refractive surgery: description, results, and limitations. J Refract Surg, 2012 Mar; 28(3): 224–32.
18. **Tomita, M., Waring, GO 4th, Magnago, T., et al.:** Clinical results of using a high-repetition-rate excimer laser with an optimized ablation profile for myopic correction in 10 235 eyes. J Cataract Refract Surg, 2013 Oct; 39(10): 1543–9.
19. **Venter, J.:** Wavefront-guided custom ablation for myopia using the NIDEK NAVEX laser system. J Refract Surg. 2008; 24(5): 487–493
20. **Waheed, S., Chalita, M.R., Xu, M. et al.:** Flap-induce and laser-induce ocular aberrations in a two-step procedure. J Refract Surg 2005; 21: 346–352.
21. **Yu, C.Q., Manche, E.E.:** Comparison of 2 wavefront-guided excimer lasers for myopic laser in situ keratomileusis: one-year results. J Cataract Refract Surg. 2014; 40(3): 412–422.
22. **Zhang, J., Zhou, Y., Wang, N., et al.:** Comparison of visual performance between conventional LASIK and wavefront-guided LASIK with iris-registration. Chin Med J, 2008; 121: 137–142.