

Quality of Vision After LASIK, PRK and FemtoLASIK: An Analysis Using the Double Pass Imaging System HD AnalyzerTM[®]

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Purpose: Analyze and compare the quality of vision of Photorefractive keratectomy (PRK), LASER in situ keratomileusis with mechanical microkeratome (LASIK) and femtosecond-assisted LASIK (FS-LASIK) using the double-pass imaging system HD AnalyzerTM[®].

Setting: Ophthalmology department of Centro Hospitalar Universitário do Porto (CHUPorto).

Design: Retrospective, non-randomized, single center study.

Methods: Analysis of three equivalent groups of patients submitted to PRK, LASIK and FS-LASIK at our department. The objective quality of vision assessment included the objective scatter index (OSI), the modular transfer function cutoff frequency (MTF) and the predicted visual acuity within the 100% (PVA), 20% (PVA20) and 9% contrast levels (PVA9) that were evaluated at baseline, 1st week, 1 and 6 months after surgery.

Results: 118 eyes were included: 40 underwent LASIK, 43 FS-LASIK and 35 PRK. The mean age was 30.6±4.6 years old and 56% were female. There was a significant impact concerning the type of procedure in the objective quality of vision analysis (Repeated measures ANOVA): the FS-LASIK group showed lower OSI values overtime [$F(1,2)=4.566$, $p=0.012$, OSI 0.83 ± 0.53 (FS-LASIK) vs 0.87 ± 0.47 (PRK) and 1.21 ± 1.44 (LASIK)], higher MTF values [$F(1,2)=6.569$, $p=0.002$, MTF 40.17 ± 8.33 vs 32.37 ± 11.4 (PRK) and 30.26 ± 10.28 (LASIK)], higher PVA 100% [$F(1,2)=10.871$, $p<0.001$], PVA 20% [$F(1,2)=9.737$, $p<0.001$] and PVA 9% [$F(1,2)=6.335$, $p=0.003$].

Conclusion: In our study, FS-LASIK showed an excellent optical performance through the HD AnalyzerTM technology, with significantly lower OSI and higher MTF, PVA100, PVA20 and PVA9 values. According to our results, this procedure seems to be superior to PRK and LASIK regarding visual quality objective parameters.

Keywords: quality of vision, HD analyzer, LASIK, PRK, femtosecond-assisted LASIK

Introduction

Keratorefractive surgeries, namely laser vision correction (LVC), have shown a high success concerning the correction of refractive errors, particularly myopia and myopic astigmatism. LVC is very effective increasing the uncorrected distance visual acuity (UDVA); however, these procedures may decrease the quality of vision.¹ In fact, an increase in high order aberrations (HOA) has been widely reported after keratorefractive surgery, including Photorefractive keratectomy (PRK) and LASER in situ keratomileusis (LASIK). Symptoms related to HOA such as night vision impairment, glare, halos or diplopia are the main responsible for patient dissatisfaction, even when the UDVA is 20/20 or better.¹⁻⁴ Nowadays, with the newly ablation profiles wave-front optimized and wave-front guided, those HOA are much less frequent.

Despite the paucity of studies regarding this technology, a possible way to measure vision quality is the double-pass imaging system HD AnalyzerTM, Visiometrics[®] (HDA), that is capable of measure the light scattering in the retina and the eye modulation transfer function, in various contrast conditions. Thus, the main parameters evaluated by this device are the Ocular Scatter Index (OSI) and the Modular Transfer Function (MTF). The OSI consists of an objective

evaluation of intraocular scattered light and is calculated by evaluating the amount of light outside the double-pass retinal intensity image in relation to the amount of light on the center (lower values corresponds to better quality of vision). The MTF consists of the frequency at which the eye can focus an object on the retina with a contrast level of 1% (higher values corresponds to better quality of vision). This technology is able to quantify the total ocular scatter of light, and so the total ocular aberration. Thereby, by evaluating the true refractive performance of the eye, with no influence of visual cortex, this becomes a more objective measurement of vision quality than contrast sensitivity testing.^{5–7}

From our knowledge, there are only a few publications regarding vision quality after LASIK and PRK using this technology. Therefore, the purpose of our work was to analyze and compare the objective performance in the quality of vision of three LASER procedures: PRK, LASIK with mechanical microkeratome (LASIK-MMK) and femtosecond-assisted LASIK (FS-LASIK) using this HD Analyzer™, Visiometrics® double-pass imaging system.

Materials and Methods

This study was conducted in accordance with the tenets of the Declaration of Helsinki (1964). All patients provided informed consent for treatment, and the study protocol complies with the requirements of the institute's committee on human research ("Departamento de Ensino, Formação e Investigação") of Centro Hospitalar Universitário do Porto (CHUPorto).

This is a retrospective, single-center analysis of three equivalent groups of patients submitted to PRK, LASIK and FS-LASIK. Patients with corneal diseases, history of previous uveitis or eyes with previous ophthalmology surgeries were excluded. We also exclude patients that had some complication during the procedure, such as incomplete flap creation.

Demographic data (age and gender), spherical equivalent (SE), sphere and cylinder values and best corrected visual acuity (BCVA) in decimal scale were collected at baseline for all groups.

The objective quality of vision assessment performed by HDA evaluated the OSI, the MTF and the predicted visual acuities (decimal) within the 100% (PVA100), 20% (PVA20) and 9% contrast levels (PVA9). These outcomes were collected at baseline, at 1st week, 1st and 6th months after procedure and were compared between the three groups. Patients without HD Analyzer™ evaluation prior to surgery were excluded.

The uncorrected distance visual acuity (UDVA) was measured at 1st week, 1 and 6 months after surgery and compared among the 3 groups. Then, a correlation analysis was performed to study possible correlations between HDA parameters at 6 months with prior refraction (sphere, cylinder and spherical equivalent), and also with final UDVA.

LVC was performed with the Excimer laser Wavelight®EX500 (Alcon), using the wavefront-optimized ablation profile with an optical zone of 6 mm. The Femtolaser was the Wavelight®FS200 (Alcon).

Statistical Analysis

Statistical analysis was performed using IBM SPSS® software, version 27.0 (Armonk, NY: IBM Corp). A normality test was performed on all continuous variables, using the Kolmogorov–Smirnov test. A Repeated measures ANOVA within-between subjects was used to compare data concerning HDA quality of vision parameters (OSI, MTF, PVA100, PVA20 and PVA9) between the three groups. One-way ANOVA was used to compare UDVA in the 1st week, 1st and 6th months between the three groups. The correlation analysis was done using Pearson's correlation coefficient.

The results of continuous variables are expressed as mean \pm standard deviation (SD), and a value of $p < 0.05$ was considered statistically significant.

Results

Baseline Characteristics

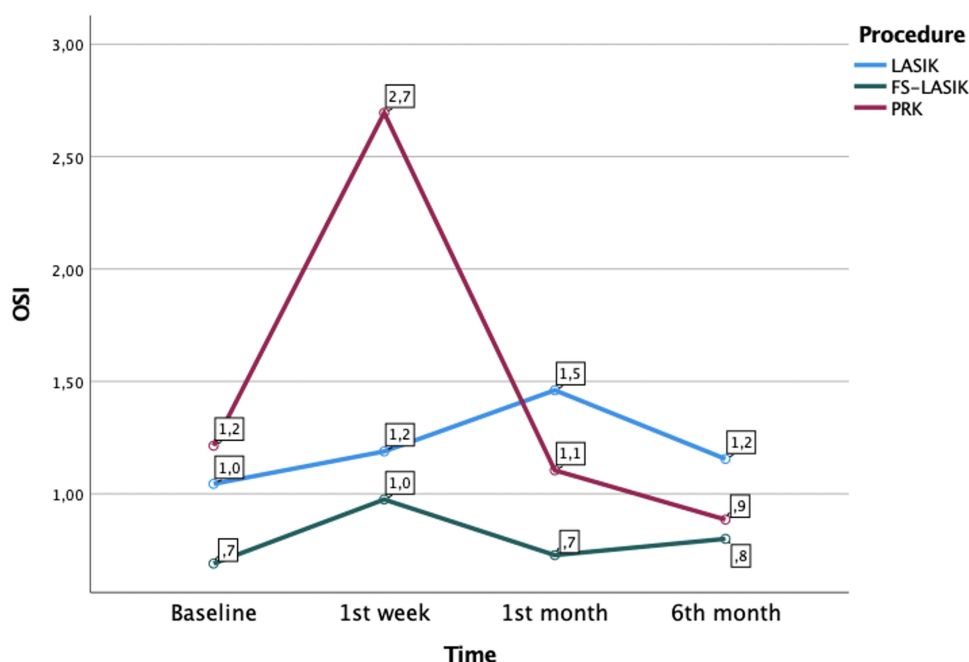
118 eyes from 66 patients were included: 43 eyes underwent FS-LASIK (36.4%), 40 eyes underwent LASIK (33.9%) and 35 eyes belonged to the PRK group (29.7%). Thirty-seven patients were female (56.1%). The mean age was 30.6 ± 4.6 years-old, with no differences between groups ($p = 0.546$). The mean spherical equivalent was -2.88 ± 1.73 diopters (D), being significantly more myopic in the FS-LASIK group ($p < 0.001$); the sphere value was -2.46 ± 1.85 D and was also more myopic in the FS-LASIK group ($p < 0.001$); the cylinder value was -0.91 ± 1.24 D, without differences between the 3 groups ($p = 0.102$). The BCVA was 0.98 ± 0.06 ($p = 0.301$). Baseline data is resumed in Table 1.

Table 1 Baseline Characteristics

		Differences (Groups) (One-Way ANOVA)
Age (Mean±SD)	30.6±4.6 years-old	F (2; 115)= 0.608, p=0.546
Gender	37 Female (56.1%) 29 Male (43.9%)	
Spherical equivalent	Total: -2.88±1.73 - FS-LASIK: -3.64±1.81 - LASIK: -2.66±1.54 - PRK: -2.18±1.49	F(2;115)=8.274, p<0.001
Sphere	Total: -2.46±1.85 - FS-LASIK: -3.26±1.78 - LASIK: -2.35±1.64 - PRK: -2.46±1.85	F(2;115)=8.858, p<0.001
Cylinder	Total: -0.91±1.24 - FS-LASIK: 1.11±1.09 - LASIK: 0.81±1.05 - PRK: 1.06±1.01	F(2;115)=2.327, p=0.102
BCVA (decimal scale)	0.98±0.06	F(2;115)=1.212, p=0.301

Objective Quality of Vision Assessment (HD Analyzer[®])

The OSI showed lower values overtime in the FS-LASIK group comparing to both PRK and LASIK groups [Repeated measures ANOVA within-between subjects F (2.16; 203.03) = 12.673, p<0.001; post-hoc pairwise comparison (Bonferroni) showed lower levels of OSI in FS-LASIK group vs PRK and LASIK]. Although baseline levels of OSI seem to be lower in the FS-LASIK group (0.87±0.55 vs 1.03±0.95 in the LASIK group and 1.03±0.68 in the PRK group), it was not statistically significant (p=0.074). The value of OSI in the 1st week was much higher in the PRK group (2.70±2.25) than in the other groups (1.19±0.62 and 0.98±0.60, in LASIK and FS-LASIK, respectively). Figure 1 represents OSI's value in all time points.

**Figure 1** OSI variation.

The MTF showed significantly higher values in the FS-LASIK group in all time points comparing to both PRK and LASIK [Repeated measures ANOVA within-between subjects $F(2.2; 4.4) = 14.468$, $p < 0.001$; post-hoc pairwise comparison (Bonferroni) showed higher levels overtime of MTF in FS-LASIK group vs PRK and LASIK]. Similarly, the value of MTF in the 1st week was much lower in the PRK group (18.91 ± 9.2) than in the other groups (33.6 ± 9.1 and 36.2 ± 10.4 , in LASIK and FS-LASIK, respectively). **Figure 2** represents MTF values at all time points.

Figure 3 represents PVA100, PVA20 and PVA9 values at all time points. The PVA showed to be higher in the FS-LASIK comparing to PRK and LASIK groups in all time points with 100% contrast [$F(2.02; 24.904) = 7.542$, $p < 0.001$, post-hoc pairwise comparison (Bonferroni) showed higher levels of PVA100% in FS-LASIK group vs PRK and LASIK ($p < 0.001$)], with 20% contrast [$F(2.39; 16.24) = 4.537$, $p < 0.001$, post-hoc pairwise comparison (Bonferroni) showed higher levels of PVA20 in FS-LASIK group vs PRK and LASIK ($p < 0.001$)] and 9% of contrast levels [$F(2.63; 244.56) = 5.761$, $p < 0.001$, post-hoc pairwise comparison (Bonferroni) showed higher levels of PVA9% in FS-LASIK group vs PRK and LASIK ($p < 0.001$)] **Figure 3** represents PVA values at all time points.

All collected data concerning HD Analyze[®] parameters are resumed in **Table 2**.

Uncorrected Distance Visual Acuity (UDVA)

One week after the procedure, patients submitted to PRK experienced a significantly lower UDVA than the other groups, which is in accordance with the results obtained in the HDA parameters [0.64 ± 0.17 (PRK) vs 0.91 ± 0.16 (LASIK) and 1.08 ± 0.15 (FS-LASIK); One-way ANOVA $F(2; 115) = 62.00$; $p < 0.001$].

UDVA was significantly higher in the FS-LASIK group compared to PRK and LASIK at 1st month [1.17 ± 0.12 vs 0.98 ± 0.12 (LASIK) and 0.98 ± 0.12 (PRK); One-way ANOVA $F(2; 115) = 10.096$; $p < 0.001$, post-hoc (Bonferroni test): FS-LASIK values were higher vs LASIK and vs PRK ($p < 0.001$)] and 6 months after surgery [1.17 ± 0.12 vs 1.02 ± 0.11 (LASIK) and 1.00 ± 0.09 (PRK); One-way ANOVA: $F(2; 115) = 17.894$; $p < 0.001$, post-hoc (Bonferroni test): FS-LASIK values were higher vs LASIK and vs PRK ($p < 0.001$)].

Data concerning UDVA is represented in **Figure 4**.

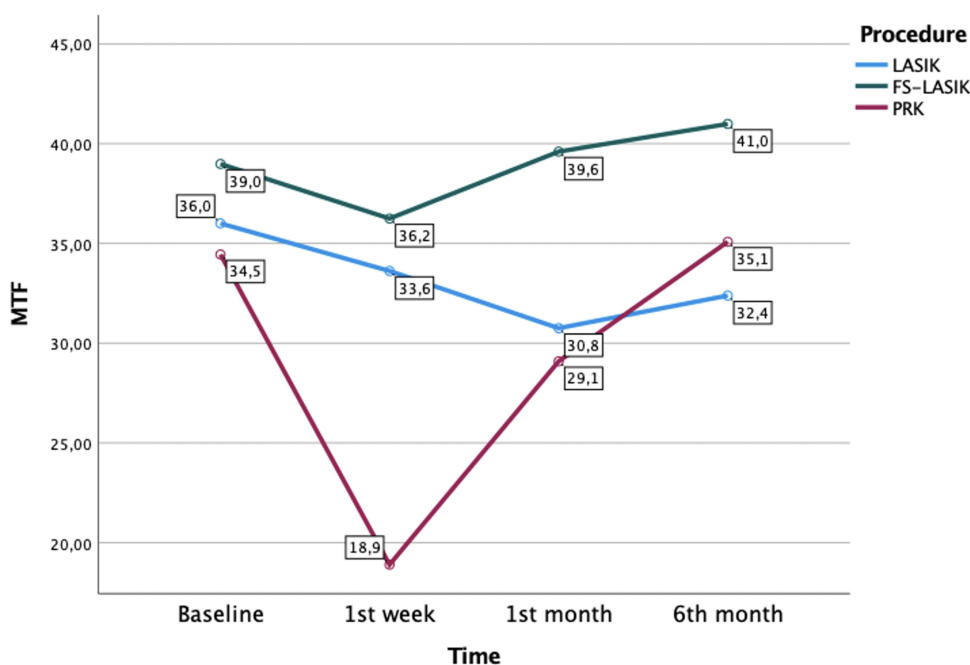


Figure 2 MTF variation.

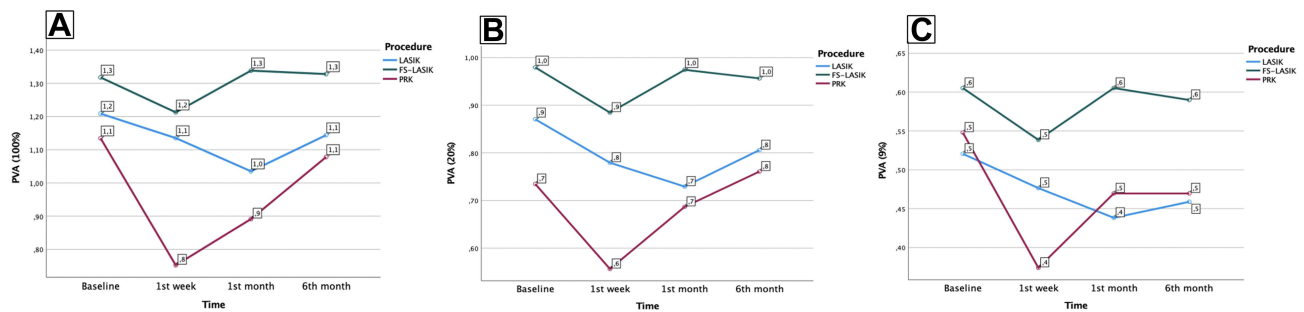


Figure 3 PVA values during follow-up. (A) PVA100, (B) PVA20, (C) PVA9.

Correlation Analysis

Correlation analysis was performed in order to search possible correlations between previous refraction (SE, sphere and cylinder) and baseline OSI and MTF; between previous refraction and vision quality parameters at 6th month (OSI and MTF), in order to know if higher refractive errors that needed a deeper ablation influenced the quality of vision; and between vision quality parameters (OSI and MTF) and UDVA at 6th month. To favor the interpretation of the results, the correlations with SE, sphere and cylinder values were performed with its absolute value.

Baseline values of OSI showed a positive correlation with baseline cylinder values ($R=0.402$, $p<0.001$), but not with the SE ($R=-0.131$, $p=0.158$) and sphere values ($R=-0.091$, $p=0.325$). The same was observed with baseline values of MTF and baseline refraction: a negative correlation with cylinder ($R=-0.386$, $p<0.001$), and no correlation with SE ($R=0.087$, $p=0.347$) and sphere values ($R=0.106$, $p=0.265$).

Quality of vision parameters (OSI and MTF) at 6th month did not correlate with final (6th month) refraction ($p>0.05$) but showed correlation with UDVA at 6th month: OSI and UDVA at 6 months (inverse correlation: $R=-0.478$, $p<0.001$); MTF and UDVA at 6 months (positive correlation: $R=0.359$, $p<0.001$). OSI and MTF at 6th month showed an inverse and strong correlation with each other ($R=-0.585$, $p<0.001$).

Table 3 shows all correlation analysis, with statistically significant values in bold.

Discussion

The light scatter measured by the HD Analyzer can occur anywhere along the optical pathway, including the tear film, the cornea, the iris or pupil margin, the lens, the vitreous media, and the retina. Thus, the HD AnalyzerTM has many applications in Ophthalmology, including early cataract diagnosis, dry eye diagnosis in asymptomatic but quality-affected patients and refractive treatment selection and evaluation of outcomes after refractive procedures.^{5,6} As an example, Zafar et al studied the objective measurements of visual quality using the HD Analyzer after Nd:YAG posterior capsulotomy, showing a significant improvement after the procedure.⁶

Other applications of this technology in refractive surgery beyond laser vision correction (LVC) have been published. A study conducted by Baptista et al studied visual quality with the use of the HD Analyzer[®] and patient satisfaction with a quality-of-life questionnaire after phakic IOL implantation. They concluded that both the Visian[®] ICLV4cTM and the Artiflex[®] showed excellent optical performance through the HD AnalyzerTM technology, with no statistically significant differences between the 2 types of phakic IOL, despite better UDVA in the Artiflex[®] group.⁷

While observing the graphics represented on Figures 1–4, concerning the comparison of objective quality of vision parameters between the 3 types of procedures (PRK, FS-LASIK and LASIK), we easily understand that at 1st week all parameters show highly different values in the PRK group. This could explain why these patients experience a slower recovery of visual acuity and visual quality. However, these differences disappear in the first month of follow-up, and at month 6 PRK seems to exhibit more satisfactory values of visual quality compared to traditional LASIK, although no statistically significant differences were observed between these two groups.

Table 2 HD Analyzer® Quality of Vision Parameters

	OSI			MTF			PVA100			PVA20			PVA9		
	FS-LASIK	LASIK	PRK	FS-LASIK	LASIK	PRK	FS-LASIK	LASIK	PRK	FS-LASIK	LASIK	PRK	FS-LASIK	LASIK	PRK
Baseline	0.70 ±0.55	1.03 ±0.95	1.21 ±0.68	39.01 ±13.03	36.01 ±12.72	34.45 ±13.26	1.32 ±0.40	1.21 ±0.41	1.13 ±0.51	0.98 ±0.40	0.87 ±0.33	0.73 ±0.39	0.61 ±0.25	0.52 ±0.18	0.55 ±0.34
1st week	0.98 ±0.60	1.19 ±0.62	2.70 ±2.25	36.25 ±10.42	33.62 ±9.12	18.91 ±9.19	1.21 ±0.37	1.14 ±0.32	0.75 ±0.39	0.88 ±0.30	0.78 ±0.24	0.56 ±0.38	0.54 ±0.19	0.48 ±0.15	0.37 ±0.29
1st month	0.73 ±0.21	1.46 ±1.80	1.10 ±1.32	39.57 ±2.81	30.76 ±11.68	29.10 ±10.49	1.34 ±0.10	1.04 ±0.41	0.89 ±0.31	0.97 ±0.06	0.73 ±0.32	0.69 ±0.24	0.61 ±0.06	0.44 ±0.19	0.47 ±0.25
6th month	0.76 ±0.10	1.16 ±2.02	0.89 ±0.56	40.99 ±2.00	32.39 ±11.47	35.09 ±10.29	1.33 ±0.10	1.14 ±0.39	1.08 ±0.41	0.96 ±0.10	0.81 ±0.31	0.76 ±0.27	0.59±0.15	0.46 ±0.18	0.47 ±0.17

Table 3 Correlation Analysis Using Pearson's Correlation

Baseline Refraction and Baseline Quality of Vision	
OSI and SE	R=-0.131, p=0.158
OSI and Sphere	R=-0.091, p=0.325
OSI and Cylinder	R=0.402, p<0.001
MTF and SE	R=0.087, p=0.347
MTF and Sphere	R=0.106, p=0.254
MTF and Cylinder	R=-0.386, p<0.001
Baseline Refraction and Final (6 Months) Quality of Vision	
OSI and SE	R=0.098, p=0.292
OSI and Sphere	R=0.113, p=0.223
OSI and Cylinder	R=-0.055, p=0.554
MTF and SE	R=0.107, p=0.25
MTF and Sphere	R=0.093, p=0.32
MTF and Cylinder	R=-0.091, p=0.33
UDVA and Final Quality of Vision (6m)	
OSI and UDVA	R=-0.478, p<0.001
MTF and UDVA	R=0.359, p<0.001
Final OSI and MTF	R=-0.585, p<0.001

This slower recovery was also noticed by Gao H. et al, that in their study compared vision quality after FS-LASIK and PRK with the use of mitomycin C, using a novel computer-based quick contrast sensitivity function (qCSF) test. They concluded that quality of vision recovery after FS-LASIK occurs in the 1st week and 1 month after PRK-MMC.⁸

Only a few published studies have compared optical quality before and after LVC.⁸⁻¹² Jung et al concluded that the optical quality 3 months after LVC recovered to baseline levels, without statistically significant differences between PRK and FS-LASIK. They also showed a slower recovery in the PRK group (1 to 3 months versus FS-LASIK that recovered in 1 week).⁹ Ondategui et al evaluated optical quality using a double-pass system preoperatively and three months after PRK and LASIK assisted with microkeratome. Their results suggested that optical quality was reduced after PRK and LASIK compared to baseline values, with no significant differences between the two surgical techniques.¹⁰

According to our results, FS-LASIK showed a significantly better quality of vision in the HDA evaluation and UDVA compared to both LASIK and PRK, with no differences regarding these last two procedures. These results, particularly the better results of FS-LASIK over LASIK assisted with mechanical microkeratome may be explained by the differences in flap creation. The introduction of the Femtosecond (FS) LASER, since 2001, brought more facility in flap creation and has continued to evolve until recent years.¹³

The microkeratome-assisted flaps have a meniscus shape (thinner at the center than in the edges, while the FS technology allows the creation of more uniform and regular flaps, with a planar shape and less imperfections than microkeratomes. Additionally, FS-assisted flap thickness can be regulated by the surgeon and enable thinner flaps (we usually perform flaps with 110 µm versus the 120 µm with microkeratome). This has the advantage of increasing the residual stromal bed (RSB), making the procedure safer when treating higher refractive errors. FS-LASER flaps' have been associated with an announced better quality of vision (less induction of high order aberrations and better contrast sensibility), and are also associated with a smaller number of complications, such as risk of infection and flap

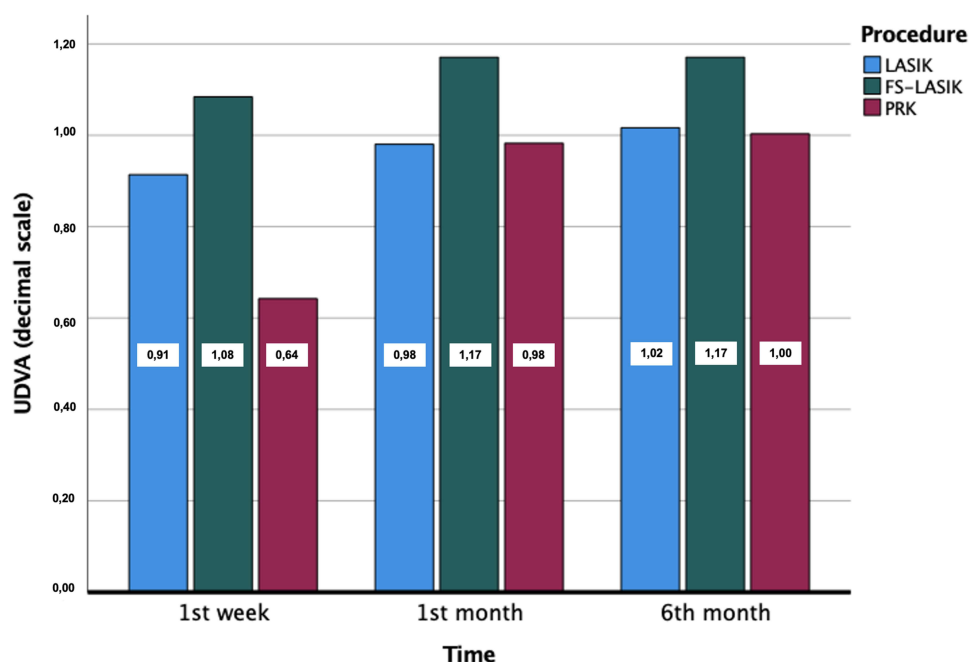


Figure 4 Uncorrected distance visual acuity (UDVA) in decimal scale.

displacement, less intraocular pressure variation during the procedure (despite longer treatment time), better uncorrected visual acuity, less dry eye disease and less effect on corneal sensitivity.^{14–16} These facts are in accordance with our results.

The PRK showed better results of OSI and MTF comparing to LASIK with microkeratome, although they were statistically different from the FS-LASIK group. Although the absence of a flap creation, lower association with high order aberration's induction and less dry eye disease, it is known that PRK requires a few months to achieve haze resolution and refraction stability.¹⁷ In our study, the final evaluation was performed 6 months after the procedure, which did not evaluate real long-term quality of vision outcomes. Maybe if this evaluation of vision quality with the HDA was performed with a longer follow-up, the results of PRK could be similar to FS-LASIK.

The authors recognize the retrospective design and absence of a longer follow-up as the major limitations of this study. Nevertheless, there are a paucity of reports regarding this technology, and this could encourage more studies with larger samples and larger follow-up that would be necessary in order to strengthen these findings.

Conclusion

In our study, FS-LASIK showed an excellent optical performance through the HD Analyzer[®] technology, with significantly lower OSI and higher MTF, PVA100, PVA20 and PVA9 values compared to PRK and traditional LASIK.

Also, FS-LASIK showed a faster recovery regarding visual acuity and quality of vision compared to the other procedures.

According to our results, there seems to be a direct correlation between these parameters and uncorrected visual acuity, which enforces the idea that the HD Analyzer should be included in the analysis of all patients submitted to keratorefractive procedures.

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