Comparison of efficacy and visual quality after CWFG-FS-LASIK, AF-FS-LASIK and SMILE for correcting myopia with asymmetry mid-to-high astigmatism

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Research article

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Abstract

Background The individualized ablation is not only able to correct corneal low-order aberrations but also improve the corneal high-order aberrations in corneal asymmetry patients. In this study, we compared the effect of patients with mid-to-high astigmatism asymmetric corneas (1-4D) after three different surgical methods: Selective coma guidance femtosecond Laser in-situ keratomileusis (CWFG-FS-LASIK),Aberration-Free femtosecond Laser in-situ keratomileusis (AF-FS-LASIK) and Small incision lenticule (SMILE).

Methods One hundred and fourteen eyes from 58 patients were enrolled in the retrospective study. We measured and compared the best corrected visual acuity (BCVA), uncorrected visual acuity (UCVA), residual astigmatism, total coma, vertical coma (Z3-1), horizontal coma (Z31), Modulation Transfer Function (MTF) and Point Spread Function (PSF) at preoperation and postoperation after three months.

Results Visual acuity of patients in three groups was increased after surgeries, but the improvements of visual acuity and residual astigmatism among them were no significant differences. However, the improvements of 4mm and 6mm total coma, Z3-1 and Z31 in CWFG-FS-LASIK were superior than in AF-FS-LASIK and SMILE. Consistent with this, the improvements of MTF and PSF (3mm and 5mm) in CWFG-FS-LASIK were better than in AF-FS-LASIK and SMILE.

Conclusions In surgeries for treating patients with mid-to-high astigmatism in asymmetric corneas, the selective coma-guided mode was able to decrease the coma of original cornea, improve visual acuity and optimize the visual quality of patients.

Background

Corneal high-order aberrations (HOAs) are one of the main factors affecting postoperative visual quality after refractive surgery. The HOAs are closely related to corneal aberrations of the preoperative or intraoperative aberrations, and also associated with corneal repairing after surgery. With the development of refractive surgery, a fixed surgical method may not be suitable for all patients with ametropia, especially in patients with mid-to-high astigmatism in asymmetric corneas, who usually accompany by corneal aberrations increased. Whereas, conventional corneal refractive surgeries may increase the original corneal asymmetry and reduce the postoperative visual quality of patients. Therefore, the individualized ablation which is not only able to correct corneal low-order aberrations, but improve the corneal high-order aberrations, especially coma, caused by preoperative corneal morphological asymmetry is becoming more advantage. In this study, SCHWIND AMARIS excimer laser from Germany was used Keratron scout corneal topographic map guided the treatment of patients with high astigmatism in the mode of CWFG-FS-LASIK and in the mode of AF-FS-LASIK and in the mode of SMILE, Observation of efficacy, report the following.

Study Group And Design

This retrospective observational study was performed at the Department of Ophthalmology, Chongqing Aier-Mega Eye Hospital, Aier Eye Hospital Group . Informed written consent was obtained from all patients. The inclusion criteria: age ≥ 18 years, total coma ≥0.25Dep, BCVA≤1.0, the Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) scanned the front surface of the cornea 3mm height difference of refractive more than 1.25D, stable refraction for two years prior. The exclusion criteria: conical cornea, scarred cornea, the lesions of the cornea, presence of active ocular disease, with autoimmunological disease. Finally, 58 patients (114 eyes), from 2018 to 2019 with a follow-time of three months, who was performed CWFG-FS-LASIK, AF-FS-LASIK or SMILE were included.

Surgical Technique

The total coma of patients was screened in natural light by a Keratron scout topographic map. We selected eight topographic map pictures import into an SCHWIND AMARIS excimer laser. All operations were performed on the patient's superior side by the same surgeon. In the CWFG-FS-LASIK patients, we designed the parameter of surgical with correcting coma before imported into a SCHWIND AMARIS excimer laser. Then, the corneal flap (the thickness is 100um, the diameter is 8.1mm) was executed by VisuMax3.0. Finally, the corneal stromal layer was removed in a selective coma-guided mode. Compared with the CWFG-FS-LASIK patients, the AF-FS-LASIK patients without correcting coma before surgery. In the SMILE patients, a 2mm curved incision at 10:30 o'clock position was executed by VisuMax3.0, corneal cap is 120um, the diameter of the lens is 6.3 to 6.5mm, or slightly adjusted. All patients were administered the Levofloxacin Drops and 4 times a day for one week, the Loteprednol Etabonate Ophthalmic Suspension 4 times a day for four weeks, the Sodium Hyaluronate Drops 4 times a day for three months.

Preoperative and Postoperative Examinations

All patients performed a general ophthalmologic examination preoperatively: visual acuity, BCVA, refraction, tonometry, slitlamp evaluation, topography specular microscopy, and fundoscopy. Three months postoperatively: UCVA, residual astigmatism, the coma (total, vertical and horizontal respectively), MTF, PSF were measured.

Statistical Analysis

All statistical analyses were performed by SPSS (version 19; SPSS Inc). Figures were drawn by GraphPad Prism (version 8; GraphPad Software). Data were presented as mean ± standard deviation. Student’s t-test for normally distributed data and Mann-Whitney test for non-normally distributed data. One-way ANOVA was used to analyze the difference among three groups of different operative methods, and LSD was used further to performed additional multiple comparison tests. $P<0.05$ were considered statistically significant.

Results

This study finally included 114 eyes (58 patients): 39 eyes (20 patients) in the CWFG-FS-LASIK group; 38 eyes (19 patients) in the AF-FS-LASIK group; 37 eyes (19 patients) in the SMILE group. Demographics of the study and the parameters of eyes included in each group are summarized. All patients with no infection; no transposition, no fold, no decentered ablation of the supracorneal flap the general situation of the patients before surgery is shown in Table 1.

Visual acuity

The BCVA of CWFG-FS-LASIK group, AF-FS-LASIK group and SMILE group were 0.0077±0.027, 0.0105±0.031 and 0.0135±0.035, respectively, with no significant difference (P>0.05). The UCVA of three groups were 0.3641±0.341, 0.3658±0.345 and 0.4351±0.344 respectively 3 months after operation, with no significant difference (P>0.05). The postoperative UCVA of patients in three groups were all promoted compared to preoperative BCVA, but the scale of promotion among them was no difference (Figure 1).

Residual astigmatism

The residual astigmatism of CWFG-FS-LASIK group, AF-FS-LASIK group and SMILE group were -0.43±0.14, -0.44 ± 0.16, -0.43 ± 0.16, respectively. There was no significant difference among the three groups (P>0.05) (Figure 2)

The change of coma aberration

We compared the total coma aberration, Z_3^{-1} and Z_3^{1} in groups after surgery in three months. The total coma aberration (4mm and 6mm) in the CWFG-FS-LASIK group decreased than preoperative data, while it increased in AF-FS-LASIK group and SMILE group. The improvement of total coma aberration in CWFG-FS-LASIK was better than other groups (Figure 3A). The 4mm Z_3^{-1} and 6mm Z_3^{-1} of CWFG-FS-LASIK group decreased after surgery, on the contrary, it increased in AF-FS-LASIK group and SMILE group. The improvement of Z_3^{-1} in CWFG- FS-LASIK group was better than other two groups (Figure 3B). Finally, we compared pre-and post-operation of the 4mm Z_3^{1} and 6mm Z_3^{1}, it significantly decreased in CWFG-FS-LASIK group but increased in AF-FS-LASIK group and SMILE group. The improvement of 4mm Z_3^{1} was better than other two groups, no significant difference in 6mm Z_3^{1} condition (Figure 3C). Pre-and post-operative data were shown in Table 2A.

The changes of MTF and PSF

The MTF and PSF were measured by I-Trace (Tracey Technologies, Houston, TX). The MTF (3mm and 5mm) in CWFG- FS-LASIK and SIMLE groups increased after 3 months, but decreased in AF-FS-LASIK group. The improvements of MTF (3mm and 5mm) in both CWFG-FS-LASIK and SMILE groups were superior than AF-FS-LASIK group (Figure 4A). In the PSF (3mm and 5mm) of three groups, the PSF of CWFG-FS-LASIK and SMILE groups were increased, but decreased in AF-FS-LASIK group. The improvements of PSF (3mm and 5mm) of CWFG- FS-LASIK and SMILE were uperior than AF-FS-LASIK (Figure 4B), the same as the MTF parameter. Pre-and post-operative data were shown in Table 2.

Discussion

Astigmatism is a type of refractive error which the eye does not focus light evenly on the retina and unable to form a clear image. The corneal astigmatism can be divided into round, oval, asymmetric bow tie shape, asymmetric bow tie shape and irregular shape according to the corneal shape,among them, the most common is asymmetrical bow-tie shape, accounting for about 50.9% [1] .Traditional corneal refractive surgery has a better effect on correcting low-order aberrations (myopia, astigmatism), but additional HOAs are often introduced after surgery, or the original high-order aberrations are increased. It is considered that the cause of the decline in postoperative visual quality [2, 3]. Postoperative HOAs are mainly derived as follow: corneal flap production and its ablation depth, the deeper the ablation, the high the HOAs introduced; the cooperation from patient and eye position during surgery; corneal wound healing, corneal morphology and biomechanics changes after surgery will also cause additional aberrations. From the clinical observation, in some obvious corneal astigmatism with asymmetric bow tie-shaped, often accompanied by HOAs, especially coma [4–6]. Visual quality is affected by coma aberrations, which is more prone to nighttime visual quality, such as halo, glare, difficulty in near vision, smearing, a poorer dark vision[7]. Therefore, for such patients who admitted with a traditional surgical method for correcting corneal refractive, the original asymmetry of the cornea may be aggravated, and increased the original HOAs that may cause a decrease of visual quality after operation [8]. In this study, patients with myopia and asymmetric mid-to-high astigmatism mainly accompanied by increased coma underwent individual treatments. The most commonly used personalized surgery is corneal topographical guidance and wavefront aberration guidance，the purpose of corneal topographical map guidance is to reduce corneal irregularity and thus reduce highpriced aberrations，corneal topography should be the first choice to guide the surger for the irregular astigmatism of cornea.Wavefront aberration guidance is based on full-eye aberrations and is affected by intraocular astigmatism such as the tear film, pupil, adjustment, and lens[9]，the operation mode guided by wavefront aberration is to directly reduce the high order aberration as the ultimate goal，it can not only improve the regularity of the anterior surface of cornea, but also make the morphology of the posterior surface of cornea more regular.The astigmatism of the asymmetric cornea was mainly due to the increase of coma, according to its direction, it is divided into $Z_3^{-1}$and Z_3^{1}, the Z_3^{-1} mainly affects the visual quality along the vertical meridian. The most of the patients we selected were vertically asymmetrical astigmatism，the increase of Z_3^{-1} was also the main factor before surgery，therefore, this study adopts the unique selective coma elimination mode of SCHWIND AMARIS excimer laser, which is more targeted. The Z_3^{-1} was eliminated, and the Z_3^{1} was improved to some extent, but not as much as the Z_3^{-1}. Fernández-Sánchez V et al [10] found that the visual quality of patients was improved after greater aberration corrected.We found that the total coma in CWFG-FS-LASIK group at 3 months after surgery was reduced compared with that before surgery, but increased in AF-FS-LASIK and SIMLE groups. This may be due to FS-LASIK are affected by flapping, coordination, tracking, and biomechanics, so it is more easily to introduce additional HOAs, however, SMILE has less factors of interference due to the lensless mode [11, 12]，compared with traditional LASIK surgery, SMLE can cause less HOAs[13, 14]，the results also showed that SMILE group had less introduction

to coma of surgical origin than AF-FS-LASIK group. In this study, there was no significantly difference of total coma between AF-FS-LASIK and SMILE. On vector analysis of coma, CWFG-FS-LASIK had a better improvement on the vertical coma, while the other groups had no significant improvement on it, even introduced a surgical source Z_3^{-1}. Meanwhile, CWFG-FS-LASIK was able to correct part Z_3^1, not in AF-FS-LASIK and SMILE. That may be related to small sample size in this study and the introduction of surgical source.

We also observed the correction of low-order aberrations in three groups for mid-to-high asymmetry astigmatism. The visual acuity of patients in three groups after 3 months was improved compared with the BCVA before surgeries, but no significant difference among groups. We used residual astigmatism for evaluating the correction of astigmatism and found that the residual astigmatism in CWFG- FS-LASIK group was low, while there was no significant difference among groups. These results showed that although CWFG-FS-LASIK was able to improve coma superior than other two surgical methods, but it had no obvious advantage in improving vision and residual astigmatism. So the surgical treatment effect in three groups are the same? Whereas, visual acuity and diopter, as low order aberrations, are primary indicators for evaluating visual quality [15, 16]. Therefore, in order to further compare the visual quality among the three groups, we selected the i-Tace inspection equipment to observe the MTF and PSF, so as to further observe the impact of the three methods on the visual quality; The MTF describes the relationship between object image contrast and optical system imaging quality at different spatial frequencies,and MTF is not affected by subjective factors, and is objectively reflect the optical imaging quality of the entire refractive system of the eyeball. The larger the MTF value, the clearer the imaging and the better the visual quality.[17]. The PSF is another an important objective indicator to measure the quality of retinal imaging. The image quality was evaluated by the size of the spot area and the intensity of the spo. In this study, we found that the visual quality in CWFG-FS-LASIK and SMILE groups improved both during the day and at night compared to before surgery, but the visual quality decreased in AF-FS-LASIK group.

Conclusions

In conclusion, the CWFG-FS-LASIK was superior to decrease coma and improve visual quality in patients of myopia with mid-to-high astigmatism.However, this study focused on the high order aberrations of the cornea, especially the coma, there are limitations that no attention was paid to the changing factors of intraocular aberrations.This study mainly discusses the analysis of relatively stable 3-month data, which needs a longer time for research. At present, in addition to the aberration-guided surgical methods, there are also the topographic map-guided surgical methods in the personalized treatment schemes. Due to the limitations of the equipment, this study has not included the corneal topographic map-guided methods for comparison,particularly accompanied corneal asymmetry than AF-FS-LASIK and SMILE. Longer-term and larger further studies will be needed.

Abbreviations

CWFG-FS-LASIK
Selective coma guidance femtosecond Laser in-situ keratomileusis
AF-FS-LASIK
Aberration-Free femtosecond Laser in-situ keratomileusis
SMILE
Small incision lenticule;BCVA:best corrected visual acuity;
UCVA
uncorrected visual acuity;Z_3^{-1}:vertical coma;Z_3^1:horizontal coma;
MTF
Modulation Transfer Function; PSF:Point Spread Function;
HOAs
High-order aberrations.

Declarations

Conflict of Interest

The authors declare that they do not have any conflict of interests.

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Availability of data and material

Available upon request from the first author: Zhongxiu Zhao.

Consent for publication

Not applicable.

Ethics approval and consent to participate

This retrospective observational study was approved by the Ethics Committee of Chongqing Aier-Mega Eye Hospital, Aier Eye Hospital Group. Informed written consent was obtained from all patients.

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Tables

Table 1 Patient characteristics

Parameter	CWFG-LASIK	AF-FS-LASIK	SMILE	*P* value
Demographics				
Age (year)	26.06±5.98	25.00±7.37	25.12±5.92	0.864
Number of eyes	39	38	37	-
Preoperative				
Sphere (D)	-4.46±1.65	-4.78±0.89	-4.58±1.18	0.601
Cylinder (D)	-1.73±0.65	-1.39±0.86	-2.26±0.43	0.273
Corneal thickness (μm)	534.60±22.34	528.00±20.54	531.10±19.92	0.843
IOP (mmHg)	15.91±3.90	14.47±2.35	15.66±4.30	0.732

IOP: Intraocular pressure

Table 2 Pre- and post-operative data of coma, MTF and PSF in three surgery methods.

Parameter	Diameter	Post-operation vs Pre-operation		
		CWFG-FS-LASIK	AF-FS-LASIK	SMILE
Total coma aberration	4mm	0.17±0.07 vs 0.29±0.04	0.34±0.10 vs 0.28±0.04	0.28±0.04 vs 0.28±0.03
	6mm	0.22±0.12 vs 0.34±0.08	0.38±0.13 vs 0.32±0.047	0.36±0.15 vs 0.33±0.04
Vertical coma aberration	4mm	0.16±0.11 vs 0.22±0.05	0.26±0.13 vs 0.21±0.05	0.27±0.13 vs 0.21±0.032
	6mm	0.20±0.11 vs 0.30±0.04	0.38±0.10 vs 0.30±0.05	0.35±0.13 vs 0.30±0.30
Horizontal coma berration	4mm	0.22±0.05 vs 0.17±0.08	0.21±0.08 vs 0.18±0.05	0.21±0.07 vs 0.18±0.03
	6mm	0.25±0.11 vs 0.28±0.08	0.31±0.11 vs 0.27±0.07	0.32±0.13 vs 0.27±0.04
MTF	3mm	0.60±0.10 vs 0.48±0.10	0.42±0.10 vs 0.48±0.09	0.53±0.09 vs 0.49±0.06
	5mm	0.42±0.05 vs 0.33±0.04	0.31±0.06 vs 0.35±0.04	0.37±0.04 vs 0.32±0.04
PSF	3mm	0.53+0.10 vs 0.40+0.13	0.35+0.13 vs 0.41+0.09	0.45+0.14 vs 0.40+0.12
	5mm	0.43+0.08 vs 0.33+0.07	0.26+0.07 vs 0.32+0.08	0.37+0.05 vs 0.33+0.07

MTF: Modulation Transfer Function, PSF: Point Spread Function

Figures

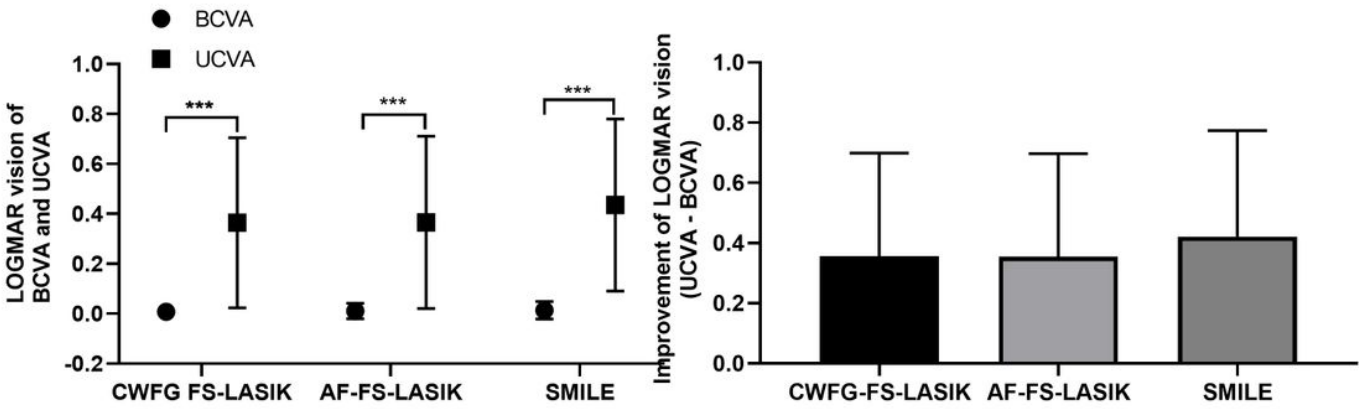

Figure 1

Comparison of visual acuity improvement before and after different surgical methods and visual acuity improvement among three groups

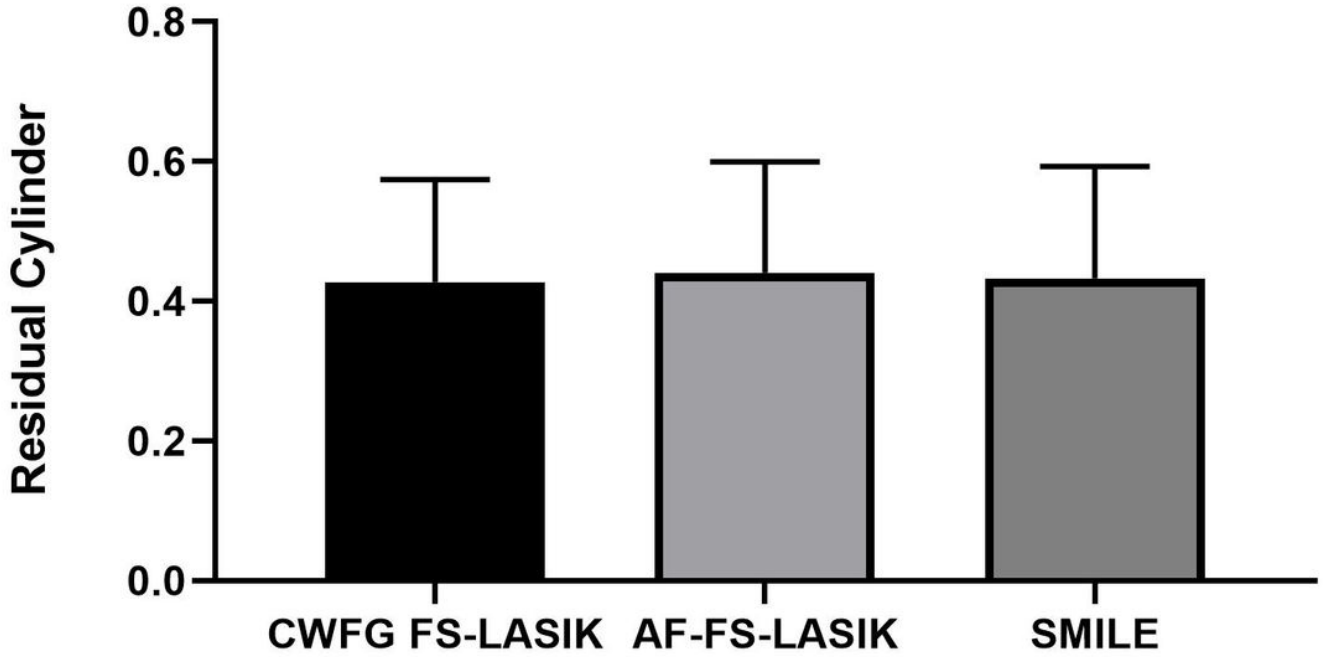

Figure 2

Residual astigmatism among three surgery methods.

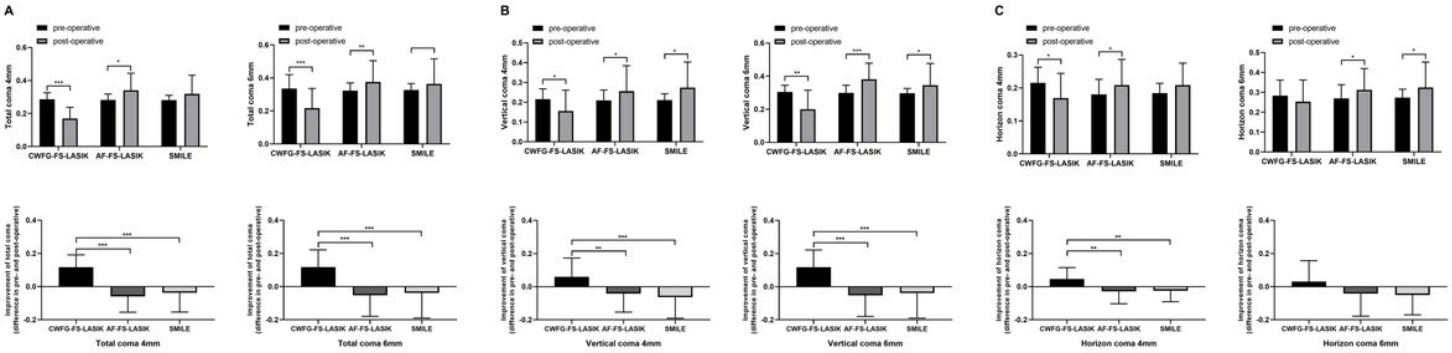

Figure 3

A The Pre- and post-operative of total coma and its improvement in three surgery methods. B The Pre- and post-operative of vertical coma and its improvement in three surgery methods. C The Pre- and post-operative of horizontal coma and its improvement in three surgery methods.

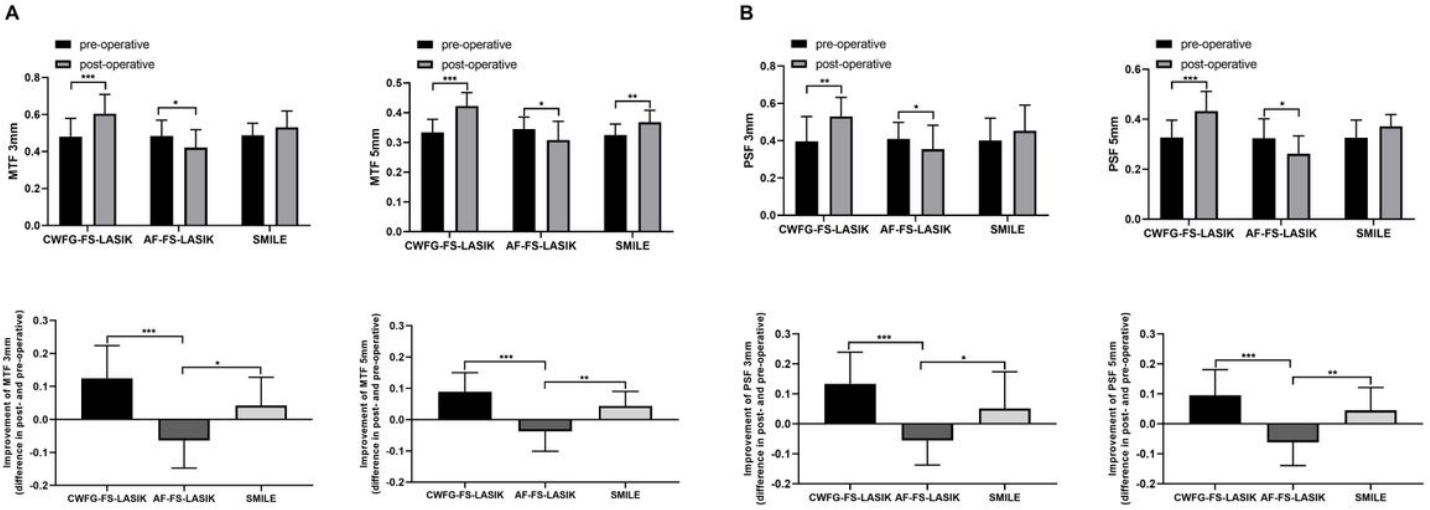

Figure 4

A The Pre- and post-operative of MTF and its improvement in three surgery methods. B The Pre- and post-operative of PSF and its improvement in three surgery methods