

· 临床研究 ·

# FS-LASIK 与 SMILE 术后角膜高阶像差变化比较

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**【摘要】** 目的 分析并比较飞秒激光辅助准分子激光角膜原位磨镶术(FS-LASIK)和飞秒激光小切口角膜基质透镜取出术(SMILE)术后角膜高阶像差(HOA)变化。方法 采用非随机对照研究方法, 纳入 2018 年 4 月至 2020 年 1 月于山东省眼科医院接受 FS-LASIK 或 SMILE 矫正的近视患者 60 例 60 眼, 均收集右眼数据纳入分析。FS-LASIK 组 30 例 30 眼, 术前等效球镜度为  $(-5.36 \pm 1.11)$  D; SMILE 组 30 例 30 眼, 术前等效球镜度为  $(-4.93 \pm 1.03)$  D。分别于术前和术后 1、3、6、12 个月采用 Pentacam 三维眼前节分析系统测定直径 6 mm 范围的角膜前表面、后表面和全角膜 HOA, 获取患者角膜总 HOA、球差、彗差和三叶草像差, 以均方根值( $\mu\text{m}$ )表示, 比较 2 个组不同时间点各指标差异。结果 术前及术后 1、3、6、12 个月 FS-LASIK 组角膜前表面 HOA 分别为  $(0.428 \pm 0.126)$ 、 $(0.775 \pm 0.169)$ 、 $(0.811 \pm 0.194)$ 、 $(0.759 \pm 0.214)$ 、 $(0.704 \pm 0.199)$   $\mu\text{m}$ , SMILE 组分别为  $(0.409 \pm 0.094)$ 、 $(0.656 \pm 0.148)$ 、 $(0.681 \pm 0.161)$ 、 $(0.668 \pm 0.175)$ 、 $(0.648 \pm 0.160)$   $\mu\text{m}$ , 总体比较差异均有统计学意义( $F_{\text{分组}} = 5.652, P = 0.024; F_{\text{时间}} = 107.169, P < 0.01$ )。与 SMILE 组相比, FS-LASIK 组术后各时间点角膜前表面总 HOA、球差明显增大, 差异均有统计学意义(均  $P < 0.05$ ); 2 个组术后各时间点角膜前表面总 HOA、球差明显大于术前, 术后 6 个月和 12 个月角膜前表面总 HOA 小于术后 3 个月, 术后 12 个月角膜前表面球差明显小于术后 1 个月和 3 个月, 差异均有统计学意义(均  $P < 0.05$ )。手术前后不同时间点角膜前表面彗差、三叶草像差总体比较差异均有统计学意义(彗差:  $F_{\text{时间}} = 47.848, P < 0.01$ ; 三叶草像差:  $F_{\text{时间}} = 2.497, P = 0.046$ ), 其中与术前比较, 2 个组术后各时间点角膜前表面彗差明显增大, 差异均有统计学意义(均  $P < 0.05$ )。2 个组间手术前后不同时间点全角膜总 HOA、球差总体比较差异均有统计学意义(总 HOA:  $F_{\text{分组}} = 8.093, P = 0.008; F_{\text{时间}} = 125.019, P < 0.01$ 。球差:  $F_{\text{分组}} = 4.771, P = 0.037; F_{\text{时间}} = 34.033, P < 0.01$ ), 其中与 SMILE 组相比, FS-LASIK 组术后各时间点全角膜总 HOA、球差明显增大, 差异均有统计学意义(均  $P < 0.05$ ); 2 个组术后各时间点全角膜 HOA、球差明显大于术前, 术后 12 个月全角膜球差明显小于术后 1 个月和 3 个月, 差异均有统计学意义(均  $P < 0.05$ )。手术前后不同时间点全角膜彗差总体比较差异有统计学意义( $F_{\text{时间}} = 30.829, P < 0.01$ ), 其中与术前比较, 2 个组术后各时间点全角膜彗差明显增大, 差异均有统计学意义(均  $P < 0.05$ )。结论 FS-LASIK 和 SMILE 术后均导致角膜前表面和全角膜总 HOA、球差和彗差增加; 相较 FS-LASIK, SMILE 术后引入了更少的角膜前表面、全角膜总 HOA 和球差。

**【关键词】** 近视; 角膜激光手术; 角膜波前像差; 飞秒激光辅助准分子激光角膜原位磨镶术; 飞秒激光小切口角膜基质透镜取出术; 高阶像差

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## Comparison of corneal higher order aberration after femtosecond laser-assisted laser in situ keratomileusis and small incision lenticule extraction

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**[Abstract] Objective** To analyze and compare the corneal higher order aberration (HOA) after femtosecond laser-assisted laser in situ keratomileusis (FS-LASIK) and small incision lenticule extraction (SMILE). **Methods** A non-randomized controlled study was conducted. Sixty myopic patients (60 eyes) who underwent FS-LASIK or SMILE correction at Shandong Eye Hospital from April 2018 to January 2020 were enrolled and the data from the right eye were collected for analysis. Thirty cases (30 eyes) who received FS-LASIK in FS-LASIK group and 30 cases (30 eyes) who received SMILE in SMILE group had a preoperative equivalent spherical diopter of  $(-5.36 \pm 1.11)$  D and  $(-4.93 \pm 1.03)$  D, respectively. The HOA of the 6-mm anterior surface, posterior surface, and whole cornea were measured before surgery and at 1, 3, 6, and 12 months after surgery using Pentacam. The root mean square values ( $\mu\text{m}$ ) of total corneal HOA, spherical aberration, coma and trefoil were obtained. Differences in the above root mean square values at different time points were compared between the two groups. The study protocol adhered to the Declaration of Helsinki and was approved by the Ethics Committee of Shandong Eye Hospital (No. SDSYKYY20180306). Written informed consent was obtained from each subject. **Results** The preoperative and 1-, 3-, 6-, 12-month postoperative total HOA of the anterior corneal surface were  $(0.428 \pm 0.126)$ ,  $(0.775 \pm 0.169)$ ,  $(0.811 \pm 0.194)$ ,  $(0.759 \pm 0.214)$ ,  $(0.704 \pm 0.199)$   $\mu\text{m}$  in the FS-LASIK group and  $(0.409 \pm 0.094)$ ,  $(0.656 \pm 0.148)$ ,  $(0.681 \pm 0.161)$ ,  $(0.668 \pm 0.175)$ ,  $(0.648 \pm 0.160)$   $\mu\text{m}$  in the SMILE group, with a significant overall difference ( $F_{\text{group}} = 5.652, P = 0.024; F_{\text{time}} = 107.169, P < 0.01$ ). Compared with SMILE group, the postoperative total HOA of anterior corneal surface and spherical aberration at different time points were increased in FS-LASIK group, showing statistically significant differences (all at  $P < 0.05$ ). Compared with before surgery, the postoperative total HOA of the anterior corneal surface and spherical aberration at different time points were increased in both groups, showing statistically significant differences (all at  $P < 0.05$ ). In the two groups, the 6- and 12-month postoperative total HOA of the anterior corneal surface were reduced in comparison with the 3-month postoperative ones of the anterior corneal surface, and the 12-month postoperative spherical aberrations of the anterior corneal surface were significantly reduced in comparison with the 1- and 3-month postoperative ones of the anterior corneal surface, showing statistically significant differences (all at  $P < 0.05$ ). There were significant differences in the coma and trefoil of the anterior corneal surface between before and after the operation (coma;  $F_{\text{time}} = 47.848, P < 0.01$ ; trefoil;  $F_{\text{time}} = 2.497, P = 0.046$ ). Compared with before surgery, the postoperative coma was significantly increased in the two groups (all at  $P < 0.05$ ). There were significant differences in total corneal HOA and spherical aberration at different postoperative time points between the two groups (total HOA;  $F_{\text{group}} = 8.093, P = 0.008; F_{\text{time}} = 125.019, P < 0.01$ . spherical aberration;  $F_{\text{group}} = 4.771, P = 0.037; F_{\text{time}} = 34.033, P < 0.01$ ). Compared with SMILE group, the total corneal HOA and spherical aberration were significantly increased in FS-LASIK group at different postoperative time points (all at  $P < 0.05$ ). Compared with before surgery, postoperative total HOA of the anterior corneal surface and spherical aberration at different postoperative time points were significantly increased in both groups (all at  $P < 0.05$ ). In both groups, the 12-month postoperative corneal spherical aberration was significantly reduced in comparison with the 1- and 3-month postoperative ones (all at  $P < 0.05$ ). There was a significant difference in coma between before and after surgery ( $F_{\text{time}} = 30.829, P < 0.01$ ). Compared with before surgery, the postoperative coma was significantly increased at different time points in both groups (all at  $P < 0.05$ ). **Conclusions** Both FS-LASIK and SMILE increase the HOA of the anterior corneal surface and the whole cornea. Compared with FS-LASIK, SMILE introduces less HOA of the anterior corneal surface and the whole cornea as well as spherical aberrations.

**[Key words]** Myopia; Corneal surgery, laser; Corneal wavefront aberration; Femtosecond-assisted laser in situ keratomileusis; Small incision lenticule extraction; Higher order aberration

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激光角膜屈光手术是矫正屈光不正的有效手段, 具有较好的安全性、稳定性、有效性和可预测性, 但研

究发现, 由于手术改变了角膜的前表面形态, 术后术眼高阶像差 (higher order aberration, HOA) 增大<sup>[1-4]</sup>, 导致



患者出现眩光、光晕及视物星芒状改变等不适症状。因此,提高裸眼视力的同时改善患者的视觉质量是激光角膜屈光手术的主要目标<sup>[5]</sup>。目前飞秒激光辅助准分子激光角膜原位磨镶术(femtosecond laser-assisted laser in situ keratomileusis, FS-LASIK)和飞秒激光小切口角膜基质透镜取出术(small incision lenticule extraction, SMILE)是矫正屈光不正的主流手术方式<sup>[6]</sup>。既往有研究发现,与 FS-LASIK 比较,SMILE 术后引入的总 HOA 更少,因此术后视觉质量更优<sup>[7-8]</sup>,但 2 种手术术后不同种类的 HOA 表现及其动态变化过程是否不同尚无定论。本研究拟对 FS-LASIK 和 SMILE 术后不同时间角膜前后表面不同种类 HOA 的变化进行比较,为激光角膜屈光手术后视觉质量的预测和评估提供参考依据。

## 1 资料与方法

### 1.1 一般资料

采用非随机对照研究方法,连续纳入 2018 年 4 月至 2020 年 1 月在山东省眼科医院接受 FS-LASIK 或 SMILE 矫正的近视患者 60 例 60 眼,均收集右眼数据纳入分析。术眼术前等效球镜度为  $-2.75 \sim -7.00$  D,平均  $(-5.14 \pm 1.08)$  D。纳入标准:年龄  $\geq 18$  周岁;屈光度至少稳定 2 年;剩余基质床厚度  $\geq 300 \mu\text{m}$ ;患者依从性好,自愿完成 12 个月的随访。排除标准:有除近视以外的其他眼部疾病;有眼部手术史;圆锥角膜和严重干眼患者;不能依照研究方案进行随访者。按照患者意愿和接受手术方式不同将受试者分为 FS-LASIK 组和 SMILE 组。FS-LASIK 组 30 例 30 眼,年龄 18~44 岁,平均  $(27.53 \pm 7.21)$  岁;术前等效球镜度为  $-2.75 \sim -7.00$  D,平均  $(-5.36 \pm 1.11)$  D。SMILE 组 30 例 30 眼,年龄 18~42 岁,平均  $(24.90 \pm 6.77)$  岁;术前等效球镜度为  $-3.50 \sim -7.00$  D,平均  $(-4.93 \pm 1.03)$  D。2 个组患者术前基线特征比较差异均无统计学意义(均  $P > 0.05$ )(表 1)。本研究遵循《赫尔辛基宣言》,研究方案经山东省眼科医院伦理委员会审核批准(批

文号:SDSYKYY20180306)。所有患者术前均了解本研究目的和方法,并自愿签署知情同意书。

### 1.2 方法

**1.2.1 手术方法** 所有手术均由同一位有经验的医生完成。术前常规消毒准备,采用 0.5% 盐酸丙美卡因滴眼液(美国 Alcon 公司)点眼 3 次进行表面麻醉。(1)FS-LASIK 患者取平卧位,采用 VisuMax 飞秒激光系统(德国 Carl Zeiss 公司)制作角膜瓣,参数设置为激光脉冲频率 500 kHz,激光能量 145 nJ,击射点间距  $4.5 \mu\text{m}$ 。切削角膜瓣直径 8.0 mm,角膜瓣蒂位于上方,边切角度为  $90^\circ$ ,瓣蒂角为  $50^\circ$ ,瓣预设厚度为  $110 \mu\text{m}$ 。激光扫描结束后,用掀瓣器将角膜瓣充分掀开,采用 Allegretto EX500 准分子激光系统(美国爱尔康公司)波前像差优化模式进行角膜基质切削,光区直径为 6.5 mm。(2)SMILE 采用 VisuMax 飞秒激光系统(德国 Carl Zeiss 公司)扫描角膜基质透镜,激光脉冲频率 500 kHz,激光能量 145 nJ,击射点间距  $4.5 \mu\text{m}$ ,帽预设厚度为  $120 \mu\text{m}$ ,角膜帽直径 7.5 mm,微透镜直径 6.5 mm,过渡区 0.1 mm,基底加厚  $15 \mu\text{m}$ ,切口长 2.47 mm,位置在  $120^\circ$ 。激光扫描结束后,分离并取出透镜。

**1.2.2 术后处理** 术后采用 0.5% 左氧氟沙星滴眼液(日本参天制药株式会社)每天点眼 4 次,连续用药 1 周;0.1% 氟米龙滴眼液(日本参天制药株式会社)每天点眼 4 次,每周递减 1 次,连续用药 4 周;0.1% 玻璃酸钠滴眼液(德国 URSAPHARM Arzneimittel GmbH 公司)每天点眼 3 次,连续用药 6 个月。

**1.2.3 随访及评估指标** 分别于术前和术后 1、3、6、12 个月采用 Pentacam 三维眼前节分析系统(德国 Oculus 公司)测定直径 6 mm 范围的角膜前表面、后表面和全角膜 HOA,获取患者角膜总 HOA、球差、彗差和三叶草像差,以均方根值( $\mu\text{m}$ )表示。记录患者术中和术后并发症发生情况。检查及数据提取均由同一位有经验的医师完成。

表 1 2 个组患者基线特征比较  
Table 1 Comparison of demographics between two groups

组别	眼数	性别 (男/女, n) <sup>a</sup>	年龄 ( $\bar{x} \pm s$ , 岁) <sup>b</sup>	等效球镜度 ( $\bar{x} \pm s$ , D) <sup>b</sup>	球镜度 ( $\bar{x} \pm s$ , D) <sup>b</sup>	柱镜度 ( $\bar{x} \pm s$ , D) <sup>b</sup>
FS-LASIK 组	30	10/20	27.53±7.21	-5.36±1.11	-5.11±1.16	-0.56±0.56
SMILE 组	30	13/17	24.90±6.77	-4.93±1.03	-4.61±1.02	-0.72±0.52
$\chi^2/t$ 值		0.635	-1.458	1.568	1.778	-1.021
$P$ 值		0.426	0.150	0.122	0.081	0.311

注:(a:  $\chi^2$  检验; b: 独立样本  $t$  检验) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
Note:(a:  $\chi^2$  test; b: Independent samples  $t$ -test) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction



### 1.3 统计学方法

采用 SPSS 22.0 统计学软件进行统计分析。计量资料数据经 Shapiro-Wilk 检验证实符合正态分布,以  $\bar{x} \pm s$  表示,计数资料采用频数表示。FS-LASIK 组与 SMILE 组间性别分布差异比较采用  $\chi^2$  检验,2 个组间计量资料差异比较均采用独立样本  $t$  检验。2 个组间手术前后不同时间点角膜 HOA 总体比较采用重复测量两因素方差分析,采用 Greenhouse-Geisser 修正违反球形假设的重复测量方差分析,多重比较采用 LSD- $t$  检验。 $P < 0.05$  为差异有统计学意义。

## 2 结果

### 2.1 2 个组术眼手术前后角膜前表面 HOA 比较

2 个组间术眼手术前后不同时间点角膜前表面总 HOA、球差总体比较差异均有统计学意义(总 HOA:  $F_{\text{分组}} = 5.652, P = 0.024; F_{\text{时间}} = 107.169, P < 0.01$ 。球差:  $F_{\text{分组}} = 6.054, P = 0.020; F_{\text{时间}} = 48.164, P < 0.01$ ),其中与 SMILE 组相比,FS-LASIK 组术后各时间点角膜前表面总 HOA、球差明显增大,差异均有统计学意义(均  $P < 0.05$ );2 个组术眼术后各时间点角膜前表面总 HOA、球差明显大于术前,术后 6 个月和 12 个月角膜前表面总 HOA 小于术后 3 个月,术后 12 个月角膜前表面球差明显小于术后 1 个月和 3 个月,差异均有统

计学意义(均  $P < 0.05$ ) (表 2,3)。2 个组间角膜前表面彗差、三叶草像差总体比较差异均无统计学意义(彗差:  $F_{\text{分组}} = 0.009, P = 0.926$ ;三叶草像差:  $F_{\text{分组}} = 0.374, P = 0.545$ );手术前后不同时间点角膜前表面彗差、三叶草像差总体比较差异均有统计学意义(彗差:  $F_{\text{时间}} = 47.848, P < 0.01$ ;三叶草像差:  $F_{\text{时间}} = 2.497, P = 0.046$ ),其中与术前比较,2 个组术眼术后各时间点角膜前表面彗差明显增大,差异均有统计学意义(均  $P < 0.05$ ) (表 4,5)。

### 2.2 2 个组术眼手术前后角膜后表面 HOA 比较

2 个组间手术前后不同时间点角膜后表面总 HOA、球差、彗差和三叶草像差总体比较差异均无统计学意义(总 HOA:  $F_{\text{分组}} = 3.442, P = 0.073; F_{\text{时间}} = 2.377, P = 0.062$ 。球差:  $F_{\text{分组}} = 3.624, P = 0.067; F_{\text{时间}} = 2.360, P = 0.087$ 。彗差:  $F_{\text{分组}} = 0.208, P = 0.652; F_{\text{时间}} = 2.198, P = 0.073$ 。三叶草像差:  $F_{\text{分组}} = 0.365, P = 0.550; F_{\text{时间}} = 2.074, P = 0.102$ ) (表 6~9)。

### 2.3 2 个组术眼手术前后全角膜 HOA 比较

2 个组间术眼手术前后不同时间点全角膜总 HOA、球差总体比较差异均有统计学意义(总 HOA:  $F_{\text{分组}} = 8.093, P = 0.008; F_{\text{时间}} = 125.019, P < 0.01$ 。球差:  $F_{\text{分组}} = 4.771, P = 0.037; F_{\text{时间}} = 34.033, P < 0.01$ ),其中与 SMILE 组相比,FS-LASIK 组术眼术后各时间点全角

表 2 2 个组手术前后不同时间点角膜前表面总 HOA 比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 2 Comparison of total HOA of anterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜前表面总 HOA				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.428±0.126	0.775±0.169 <sup>ab</sup>	0.811±0.194 <sup>ab</sup>	0.759±0.214 <sup>abc</sup>	0.704±0.199 <sup>abc</sup>
SMILE 组	30	0.409±0.094	0.656±0.148 <sup>b</sup>	0.681±0.161 <sup>b</sup>	0.668±0.175 <sup>b</sup>	0.648±0.160 <sup>b</sup>

注:  $F_{\text{分组}} = 5.652, P = 0.024; F_{\text{时间}} = 107.169, P < 0.01$ 。与 SMILE 组相比, <sup>a</sup> $P < 0.05$ ;与术前比较, <sup>b</sup> $P < 0.05$ ;与术后 3 个月相比, <sup>c</sup> $P < 0.05$ (重复测量两因素方差分析, LSD- $t$  检验) HOA: 高阶像差; FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术

Note:  $F_{\text{group}} = 5.652, P = 0.024; F_{\text{time}} = 107.169, P < 0.01$ . Compared with SMILE group, <sup>a</sup> $P < 0.05$ ; compared with preoperative, <sup>b</sup> $P < 0.05$ ; compared with 3-month postoperative, <sup>c</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD- $t$  test) HOA: higher order aberration; FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 3 2 个组手术前后不同时间点角膜前表面球差比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 3 Comparison of spherical aberration of anterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜前表面球差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.238±0.087	0.439±0.170 <sup>abc</sup>	0.443±0.170 <sup>abc</sup>	0.384±0.175 <sup>ab</sup>	0.348±0.150 <sup>ab</sup>
SMILE 组	30	0.240±0.077	0.364±0.080 <sup>bc</sup>	0.357±0.100 <sup>bc</sup>	0.319±0.116 <sup>b</sup>	0.288±0.085 <sup>b</sup>

注:  $F_{\text{分组}} = 6.054, P = 0.020; F_{\text{时间}} = 48.164, P < 0.01$ 。与 SMILE 组相比, <sup>a</sup> $P < 0.05$ ;与术前比较, <sup>b</sup> $P < 0.05$ ;与术后 12 个月比较, <sup>c</sup> $P < 0.05$ (重复测量两因素方差分析, LSD- $t$  检验) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术

Note:  $F_{\text{group}} = 6.054, P = 0.020, F_{\text{time}} = 48.164, P < 0.01$ . Compared with SMILE group, <sup>a</sup> $P < 0.05$ ; compared with preoperative, <sup>b</sup> $P < 0.05$ ; compared with 12-month postoperative, <sup>c</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD- $t$  test) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 4 2 个组手术前后不同时间点角膜前表面彗差比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 4 Comparison of coma of anterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜前表面彗差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.155±0.109	0.330±0.167 <sup>a</sup>	0.379±0.188 <sup>a</sup>	0.359±0.206 <sup>a</sup>	0.334±0.186 <sup>a</sup>
SMILE 组	30	0.144±0.093	0.332±0.174 <sup>a</sup>	0.367±0.175 <sup>a</sup>	0.370±0.175 <sup>a</sup>	0.361±0.160 <sup>a</sup>

注:  $F_{\text{分组}} = 0.009, P = 0.926; F_{\text{时间}} = 47.848, P < 0.01$ . 与术前比较, <sup>a</sup> $P < 0.05$  (重复测量两因素方差分析, LSD-*t* 检验) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
 Note:  $F_{\text{group}} = 0.009, P = 0.926; F_{\text{time}} = 47.848, P < 0.01$ . Compared with preoperative, <sup>a</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD-*t* test)  
 FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 5 2 个组手术前后不同时间点角膜前表面三叶草像差比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 5 Comparison of trefoil of anterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜前表面三叶草像差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.077±0.048	0.105±0.098 <sup>a</sup>	0.114±0.095 <sup>a</sup>	0.100±0.049 <sup>a</sup>	0.106±0.067 <sup>a</sup>
SMILE 组	30	0.073±0.049	0.090±0.069 <sup>a</sup>	0.087±0.054 <sup>a</sup>	0.107±0.074 <sup>a</sup>	0.103±0.082 <sup>a</sup>

注:  $F_{\text{分组}} = 0.374, P = 0.545; F_{\text{时间}} = 2.497, P = 0.046$ . 与术前比较, <sup>a</sup> $P < 0.05$  (重复测量两因素方差分析, LSD-*t* 检验) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
 Note:  $F_{\text{group}} = 0.374, P = 0.545; F_{\text{time}} = 2.497, P = 0.046$ . Compared with preoperative, <sup>a</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD-*t* test)  
 FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 6 2 个组手术前后不同时间点角膜后表面总 HOA 比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 6 Comparison of total HOA of posterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜后表面总 HOA				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.211±0.027	0.240±0.054	0.238±0.071	0.227±0.037	0.224±0.045
SMILE 组	30	0.210±0.040	0.218±0.038	0.219±0.034	0.213±0.038	0.210±0.043

注:  $F_{\text{分组}} = 3.442, P = 0.073; F_{\text{时间}} = 2.377, P = 0.062$  (重复测量两因素方差分析) HOA: 高阶像差; FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
 Note:  $F_{\text{group}} = 3.442, P = 0.073; F_{\text{time}} = 2.377, P = 0.062$  (Two-way repeated measures ANOVA) HOA: higher order aberration; FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 7 2 个组手术前后不同时间点角膜后表面球差比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 7 Comparison of spherical aberration of posterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜后表面球差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.157±0.032	0.165±0.031	0.164±0.031	0.163±0.028	0.165±0.028
SMILE 组	30	0.145±0.027	0.152±0.038	0.159±0.029	0.152±0.028	0.153±0.030

注:  $F_{\text{分组}} = 3.624, P = 0.067; F_{\text{时间}} = 2.360, P = 0.087$  (重复测量两因素方差分析) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
 Note:  $F_{\text{group}} = 3.624, P = 0.067; F_{\text{time}} = 2.360, P = 0.087$  (Two-way repeated measures ANOVA) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 8 2 个组手术前后不同时间点角膜后表面彗差比较 ( $\bar{x} \pm s, \mu\text{m}$ )

Table 8 Comparison of coma of posterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜后表面彗差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.038±0.023	0.046±0.029	0.047±0.028	0.038±0.027	0.040±0.026
SMILE 组	30	0.040±0.022	0.048±0.024	0.046±0.021	0.041±0.028	0.045±0.024

注:  $F_{\text{分组}} = 0.208, P = 0.652; F_{\text{时间}} = 2.198, P = 0.073$  (重复测量两因素方差分析) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
 Note:  $F_{\text{group}} = 0.208, P = 0.652; F_{\text{time}} = 2.198, P = 0.073$  (Two-way repeated measures ANOVA) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

膜总 HOA、球差明显增大,差异均有统计学意义(均  $P < 0.05$ );2 个组术眼术后各时间点全角膜总 HOA、球差明显大于术前,术后 12 个月全角膜球差明显小于术后 1 个月和 3 个月,差异均有统计学意义(均  $P < 0.05$ )(表 10,11)。2 个组间术眼全角膜彗差、三叶草像差总体比较差异均无统计学意义(彗差:  $F_{\text{分组}} = 0.244, P = 0.625$ ;三叶草像差:  $F_{\text{分组}} = 0.923,$

$P = 0.344$ )。手术前后不同时间点术眼全角膜彗差总体比较差异有统计学意义( $F_{\text{时间}} = 30.829, P < 0.01$ ),其中与术前比较,2 个组术眼术后各时间点全角膜彗差明显增大,差异均有统计学意义(均  $P < 0.05$ )。手术前后不同时间点术眼全角膜三叶草像差总体比较差异无统计学意义( $F_{\text{时间}} = 0.952, P = 0.437$ )(表 12,13)。

表 9 2 个组手术前后不同时间点角膜后表面三叶草像差比较( $\bar{x} \pm s, \mu\text{m}$ )

Table 9 Comparison of trefoil of posterior corneal surface at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点角膜后表面三叶草像差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.021±0.009	0.022±0.018	0.020±0.011	0.024±0.012	0.018±0.009
SMILE 组	30	0.019±0.011	0.022±0.009	0.021±0.011	0.020±0.009	0.019±0.007

注:  $F_{\text{分组}} = 0.365, P = 0.550; F_{\text{时间}} = 2.074, P = 0.102$ (重复测量两因素方差分析) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术

Note:  $F_{\text{group}} = 0.365, P = 0.550; F_{\text{time}} = 2.074, P = 0.102$  (Two-way repeated measures ANOVA) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 10 2 个组手术前后不同时间点全角膜总 HOA 比较( $\bar{x} \pm s, \mu\text{m}$ )

Table 10 Comparison of total corneal HOA at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点全角膜总 HOA				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.426±0.127	0.801±0.166 <sup>ab</sup>	0.838±0.188 <sup>ab</sup>	0.810±0.230 <sup>ab</sup>	0.743±0.205 <sup>ab</sup>
SMILE 组	30	0.406±0.080	0.667±0.151 <sup>b</sup>	0.697±0.171 <sup>b</sup>	0.686±0.187 <sup>b</sup>	0.668±0.167 <sup>b</sup>

注:  $F_{\text{分组}} = 8.093, P = 0.008; F_{\text{时间}} = 125.019, P < 0.01$ 。与 SMILE 组相比, <sup>a</sup> $P < 0.05$ ; 与术前比较, <sup>b</sup> $P < 0.05$ (重复测量两因素方差分析, LSD-*t* 检验) HOA: 高阶像差; FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术

Note:  $F_{\text{group}} = 8.093, P = 0.008; F_{\text{time}} = 125.019, P < 0.01$ 。Compared with SMILE group, <sup>a</sup> $P < 0.05$ ; compared with preoperative, <sup>b</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD-*t* test) HOA: higher order aberration; FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 11 2 个组手术前后不同时间点全角膜球差比较( $\bar{x} \pm s, \mu\text{m}$ )

Table 11 Comparison of corneal spherical aberration at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点全角膜球差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.205±0.125	0.391±0.184 <sup>abc</sup>	0.399±0.186 <sup>abc</sup>	0.329±0.193 <sup>ab</sup>	0.296±0.161 <sup>ab</sup>
SMILE 组	30	0.200±0.077	0.325±0.089 <sup>bc</sup>	0.316±0.108 <sup>bc</sup>	0.266±0.107 <sup>b</sup>	0.248±0.096 <sup>b</sup>

注:  $F_{\text{分组}} = 4.771, P = 0.037; F_{\text{时间}} = 34.033, P < 0.01$ 。与 SMILE 组相比, <sup>a</sup> $P < 0.05$ ; 与术前比较, <sup>b</sup> $P < 0.05$ ; 与术后 12 个月比较, <sup>c</sup> $P < 0.05$ (重复测量两因素方差分析, LSD-*t* 检验) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术

Note:  $F_{\text{group}} = 4.771, P = 0.037; F_{\text{time}} = 34.033, P < 0.01$ 。Compared with SMILE group, <sup>a</sup> $P < 0.05$ ; compared with preoperative, <sup>b</sup> $P < 0.05$ ; compared with 12-month postoperative, <sup>c</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD-*t* test) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

表 12 2 个组手术前后不同时间点全角膜彗差比较( $\bar{x} \pm s, \mu\text{m}$ )

Table 12 Comparison of corneal coma at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点全角膜彗差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.155±0.101	0.336±0.171 <sup>a</sup>	0.399±0.197 <sup>a</sup>	0.384±0.220 <sup>a</sup>	0.351±0.193 <sup>a</sup>
SMILE 组	30	0.138±0.082	0.338±0.174 <sup>a</sup>	0.379±0.173 <sup>a</sup>	0.387±0.188 <sup>a</sup>	0.382±0.163 <sup>a</sup>

注:  $F_{\text{分组}} = 0.244, P = 0.625; F_{\text{时间}} = 30.829, P < 0.01$ 。与术前比较, <sup>a</sup> $P < 0.05$ (重复测量两因素方差分析, LSD-*t* 检验) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术

Note:  $F_{\text{group}} = 0.244, P = 0.625; F_{\text{time}} = 30.829, P < 0.01$ 。Compared with preoperative, <sup>a</sup> $P < 0.05$  (Two-way repeated measures ANOVA, LSD-*t* test) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction



表 13 2 个组手术前后不同时间点全角膜三叶草像差比较 ( $\bar{x} \pm s, \mu\text{m}$ )  
Table 13 Comparison of trefoil of cornea at different time points between two groups ( $\bar{x} \pm s, \mu\text{m}$ )

组别	眼数	手术前后不同时间点全角膜三叶草像差				
		术前	术后 1 个月	术后 3 个月	术后 6 个月	术后 12 个月
FS-LASIK 组	30	0.094±0.085	0.131±0.127	0.121±0.101	0.132±0.105	0.137±0.112
SMILE 组	30	0.094±0.083	0.116±0.062	0.117±0.071	0.123±0.058	0.123±0.087

注:  $F_{\text{分组}} = 0.923, P = 0.344; F_{\text{时间}} = 0.952, P = 0.437$  (重复测量两因素方差分析) FS-LASIK: 飞秒激光辅助准分子激光角膜原位磨镶术; SMILE: 飞秒激光小切口角膜基质透镜取出术  
Note:  $F_{\text{group}} = 0.923, P = 0.344; F_{\text{time}} = 0.952, P = 0.437$  (Two-way repeated measures ANOVA) FS-LASIK: femtosecond laser-assisted laser in situ keratomileusis; SMILE: small incision lenticule extraction

#### 2.4 2 个组患者并发症发生情况

所有手术均顺利完成,未出现感染等严重并发症。所有术眼术后随访期间均未出现裸眼视力下降。FS-LASIK 组未出现负压丢失、不全角膜瓣或纽扣瓣等严重并发症,SMILE 组无透镜残留、撕裂等并发症。

### 3 讨论

本研究比较了 SMILE 和 FS-LASIK 手术前后不同时间点角膜 HOA 的变化,发现 SMILE 组术后引入的角膜前表面总 HOA、球差和全角膜总 HOA、球差较 FS-LASIK 组明显减小。角膜屈光手术后 HOA 的增加主要来源于角膜瓣和角膜基质床,而角膜瓣的影响更显著<sup>[9]</sup>。SMILE 手术仅通过 2 mm 左右的小切口取出透镜,相较于 FS-LASIK 的 C 型角膜瓣,减少了角膜瓣制作复位过程中引入的术源性像差。有研究发现 SMILE 和 FS-LASIK 术后角膜像差增加量与平均角膜上皮厚度增加量呈正相关,而 SMILE 术后角膜上皮厚度变化的不均匀性小于 FS-LASIK,有可能也是导致 SMILE 术后角膜 HOA 小于 FS-LASIK 的原因<sup>[10]</sup>。此外,有研究表明 SMILE 术后切口愈合和炎症反应小于 FS-LASIK,亦有可能导致 SMILE 术后 HOA 减小<sup>[11]</sup>。

关于 SMILE 和 FS-LASIK 对角膜不同种类 HOA 的影响目前尚无结论,不少研究表明相较于 FS-LASIK,SMILE 术后引入更少的球差<sup>[7,12-15]</sup>,与本研究结果一致。分析原因有可能是准分子激光切削角膜基质边缘能量丢失产生的余弦效应而导致球差的增加,本研究中所采用的准分子激光系统具有 Q 值调整波前像差优化功能,补偿了部分周边的余弦效应,但仍显示了较明显的球差增加。Gyldenkerne 等<sup>[12]</sup>研究发现,FS-LASIK 比 SMILE 术后产生更多的彗差。武志清等<sup>[7]</sup>研究发现,SMILE 术后的彗差改变以垂直方向为主,分析可能与手术切口方向有关。本研究通过比较发现 SMILE 组和 FS-LASIK 组间角膜前表面和全角膜彗差以及三叶草像差变化差异均无统计学意义。

角膜后表面像差对角膜整体像差的贡献较小,Gyldenkerne 等<sup>[12]</sup>和 Wu 等<sup>[16]</sup>发现 FS-LASIK 和 SMILE 术后引入的角膜后表面 HOA 可忽略不计。有研究发现角膜后表面 HOA 变化可以反映角膜的生物力学特征<sup>[17]</sup>。Maeda 等<sup>[18]</sup>分析角膜后表面的第 3 阶和第 4 阶 HOA 发现 LASIK 术后正常眼 HOA 为  $0.14 \pm 0.04$ ,角膜扩张者 HOA 为  $0.83 \pm 0.57$ ,而圆锥角膜后表面 HOA 为  $1.18 \pm 0.65$ 。本研究中 FS-LASIK 和 SMILE 术后 12 个月角膜后表面总 HOA 分别为  $0.224 \pm 0.045$  和  $0.210 \pm 0.043$ ,略高于 Maeda 等<sup>[18]</sup>报道的 LASIK 术后正常眼角膜后表面第 3 阶和第 4 阶 HOA。因此,研究角膜屈光术后角膜前表面和后表面 HOA 的变化,可以更好地评估屈光手术的安全性、有效性和稳定性。

本研究和既往研究均证明,FS-LASIK 和 SMILE 术后角膜前表面 HOA、球差和彗差均较术前明显增大<sup>[19-21]</sup>。Pedersen 等<sup>[22]</sup>通过对 SMILE 术后 3 个月和 3 年的随访观察发现随着术后时间的延长,角膜前表面和全角膜球差、HOA 显著减小,彗差维持稳定。本研究发现随着术后时间的延长,FS-LASIK 和 SMILE 2 种方式角膜彗差和三叶草像差维持稳定,但术后 12 个月 2 种手术方式角膜前表面球差和全角膜球差较术后 1 个月和术后 3 个月均显著减小,说明随着术后时间的延长角膜球差会显著减小,屈光术后的角膜重塑有可能是导致术后球差减小的主要原因。

综上所述,FS-LASIK 和 SMILE 术后角膜前表面和全角膜总 HOA、球差、彗差均较术前显著增大,而随着术后时间的延长球差显著减小;与 FS-LASIK 相比,SMILE 术后引入角膜前表面、全角膜总 HOA 和球差较小。但本研究样本量较小,且未针对垂直彗差、水平彗差等具体的像差进行分析,仍需扩大样本进一步研究。

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