Original Article

A comparative and prospective study of corneal biomechanics after SMILE and FS-LASIK performed on the contralateral eyes of high myopia patients

Shengyu He[#^], Yiqi Luo[#^], Yiming Ye^, Pei Chen^, Chang Liu^, Lei Lei^, Jing Zhuang^, Keming Yu^

State Key Laboratory of Ophthalmology, Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangdong Provincial Key Laboratory Ophthalmology and Visual Science, Guangdong Provincial Clinical Research Center for Ocular Diseases, Guangzhou, China

Contributions: (I) Conception and design: S He, Y Luo, K Yu, J Zhuang; (II) Administrative support: K Yu, J Zhuang; (III) Provision of study materials or patients: Y Ye, P Chen; (IV) Collection and assembly of data: L Lei, C Liu; (V) Data analysis and interpretation: S He, Y Luo, Y Ye; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work and should be considered as co-first authors.

Correspondence to: Keming Yu; Jing Zhuang. State Key Laboratory of Ophthalmology, Zhongshan Ophthalmic Center, Sun Yat-sen University, 7 Jinsui Road, Tianhe, Guangzhou 510060, China. Email: yukeming@mail.sysu.edu.cn; zhuangj@mail.sysu.edu.cn.

Background: To compare the corneal biomechanical changes after small incision lenticule extraction (SMILE) and femtosecond laser-assisted in situ keratomileusis (FS-LASIK) with the same programmed optical zone (POZ) and similar refractive correction in patients with high myopia.

Methods: In this prospective comparative study of the contralateral eye, 50 patients with high myopia with the same POZ and similar refractive correction who underwent SMILE in one eye and FS-LASIK in the other eye. Corneal biomechanical parameters and central corneal thickness (CCT) were measured using a Corvis ST II. All the patients were evaluated during follow-up visits beyond one year. Additionally, the corneal volume (CV) of the 10-mm diameter region was measured using a Pentacam.

Results: Ambrosio relational thickness to the horizontal profile (ARTh) and stiffness parameter A1 (SP-A1) decreased significantly after SMILE and FS-LASIK, whereas deformation amplitude ratio 2.0 mm (DA ratio 2.0 mm) and integrated radius (IR) increased significantly in both groups. The ARTh and SP-A1 were greater after SMILE than those after FS-LASIK at all the follow-up visits. In addition, there were greater amounts of CCT and CV after SMILE compared with that after FS-LASIK. Moreover, a positive correlation was found between ARTh and SP-A1 and postoperative CCT, while a negative correlation was found between IR and DA ratio 2.0 mm and postoperative CCT. A moderate correlation was observed between SP-A1 and CV after both SMILE and FS-LASIK, whereas there were no relationships between CV and ARTh, IR, or DA ratio 2.0 mm.

Conclusions: SMILE had greater CCT, CV, ARTh, and SP-A1 than FS-LASIK in high myopia with the same POZ and similar refractive correction. Our results demonstrated that SMILE had lesser effect on corneal biomechanics than FS-LASIK in high myopia.

Keywords: Corneal biomechanics; Corvis ST II; small incision lenticule extraction (SMILE); femtosecond laser-assisted in situ keratomileusis (FS-LASIK); high myopia

Submitted Jan 19, 2022. Accepted for publication May 23, 2022.
doi: 10.21037/atm-22-330
View this article at: https://dx.doi.org/10.21037/atm-22-330

^ ORCID: Shengyu He, 0000-0001-9147-2545; Yiqi Luo, 0000-0001-6352-9217; Yiming Ye, 0000-0002-0458-6673; Pei Chen, 0000-0002-4401-0628; Chang Liu, 0000-0002-9121-6012; Lei Lei, 0000-0002-5300-8351; Jing Zhuang, 0000-0001-5335-3318; Keming Yu, 0000-0003-1943-5736.

Introduction

Small incision lenticule extraction (SMILE) and femtosecond laser-assisted *in situ* keratomileusis (FS-LASIK) are increasingly becoming the advanced corneal refractive surgeries worldwide and have been proven to be effective, predictable, and safe for correcting myopia (1,2). SMILE is a flap-free technique, and the stromal lenticule is extracted through a microincision. In the FS-LASIK procedure, a broader corneal flap is created in the anterior part of the corneal stroma, which weakens the corneal biomechanics. Theoretical models have indicated that the SMILE procedure preserves more corneal stress resistance and thus achieves better corneal biomechanics than FS-LASIK (3). However, there are often discrepancies between *ex vivo* and *in vivo* biomechanics. Spiru *et al.* reported that the SMILE procedure resulted in a better corneal stress resistance than FS-LASIK in an *ex vivo* study (4). SMILE had less influence on corneal biomechanics than did LASIK *in vivo* (5,6), whereas other studies suggested that no significant differences were found in corneal biomechanics between the two groups *in vivo* (7,8). Moreover, none of these studies focused on patients with high myopia (6-8). However, more corneal tissue ablation is required in cases of high myopia, which might result in greater loss of corneal strength and increase the risk of corneal ectasia (9,10). Thus, it is important to evaluate the changes in biomechanics in patients, *in vivo*, with high myopia after SMILE and LASIK.

Clarifying corneal biomechanical changes *in vivo* is challenging. Currently, Corvis ST (Oculus Optikgeräte GmbH, Wetzlar, Germany), as a noncontact tonometer with high-speed Scheimpflug visualization of corneal deformation during a symmetrically metered air pulse, is a commercially available device to clinically evaluate the corneal biomechanical properties (11). It has been widely used to assess corneal biomechanics and clinically screening for keratoconus *in vivo* (12-14). Corvis ST II, as an upgraded version of Corvis ST software, has provided some new corneal biomechanical parameters, such as Ambrosio relational thickness to the horizontal profile (ARTh), stiffness parameter A1 (SP-A1), and corneal stress-strain (SSI) (13,15). It has been used to analyze the changes in corneal biomechanics after SMILE, FS-LASIK, laser-assisted subepithelial keratomileusis (LASEK), and photorefractive keratectomy (PRK) (16-18). Parameters from Corvis ST II might provide better evaluation of different surgeries. To date, no report has evaluated corneal biomechanics after SMILE and FS-LASIK focusing on high myopia according to parameters from Corvis ST II. Evaluating corneal biomechanics after SMILE and FS-LASIK in patients with high myopia can significantly help select the appropriate refractive surgery.

Thus, in this study, we aimed to analyze the corneal biomechanical changes after SMILE and FS-LASIK for high myopia in patients with the same programmed optical zone (POZ) and similar refractive correction. To evaluate theses biomechanics *in vivo* after SMILE and FS-LASIK more accurately, we conducted a prospective contralateral eye study using the Corvis ST II, which could eliminate individual bias, as age and individual corneal responses would be similar in the same individual. We present the following article in accordance with the STROBE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-330/rc).

Methods

Participants and design

This was a prospective comparative study of the contralateral eye. A total of 50 patients (allocation 1:1) underwent SMILE in one eye and FS-LASIK in the fellow eye from August 2019 to March 2022 at the Zhong Shan Ophthalmic Center, Sun Yat-sen University. The study was conducted in agreement with the tenets of the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Board of the Zhongshan Ophthalmic Center of Sun Yat-sen University (Identifier No. 2020KYPJ159). The informed written consent was obtained from all participants. The inclusion criteria were as follows: the manifest refraction spherical equivalent (MRSE) greater than –6 diopters (D), differences in spherical equivalent (SE) and cylinder between the paired eyes ≤1 D, and a minimum residual stromal thickness (RST) exceeding 280 μm for SMILE and 300 μm for FS-LASIK. The exclusion criteria were as follows: history of ocular trauma or surgery, ocular surface diseases like severe dry eye, corneal degeneration, active ocular or systemic disease, and keratoconus or suspicious corneal topography.

Surgical procedures

All surgeries were performed by the same experienced surgeon (KMY). In the SMILE procedure, the VisuMax femtosecond laser system (Carl Zeiss Meditec AG, Jena, Germany) was used to create the cap and stromal refractive

lenticule with a laser pulse frequency of 500 kHz. The cap thickness was 110 μm and cap diameter ranged from 7.0 to 7.7 mm. The minimum lenticule edge cut thickness was set at 10 μm. The diameter of the ablation zone (OZ) varied from 6.0 to 6.8 mm. A 2-mm incision was created at the 130° incision position. After the scanning procedure, the lenticule was dissected and removed through the small incision.

In the FS-LASIK procedure, the VisuMax femtosecond laser system was used to cut the cap. The intended flap thickness was 95 μm and its diameter varied from 8.1 mm to 8.5 mm with a superior hinge position. After the flap was lifted, the AMARIS ® 750S excimer laser (Schwind, Eye-tech-solutions, GmbH) was used to ablate the stromal bed. Excimer ablation was performed with the same OZ as the paired eye in SMILE procedure. The transition zone was set from 1.45 to 2.00 mm. The flap was repositioned after laser ablation and irrigated with sterile balanced salt solution.

The postoperative regimen included administration of topical 0.5% levofloxacin eyedrops (Tarivid; Santen, Inc., Japan), 0.25% tobramycin and dexamethasone eyedrops (Maxidex; Alcon Laboratories, Inc.) four times per day for 1 week; and 0.1% fluorometholone eyedrops (Tarivid; Santen, Inc., Japan) four times per day for 3 weeks. In addition, preservative-free lacrimal substitutes were used as needed.

Preoperative and postoperative ophthalmologic examinations

Follow-up examinations were measured at 1, 3, 6 months and more than 1 year after surgery. We performed slit-lamp examination and measured the corneal volume (CV) of a 10-mm diameter region using corneal tomography (Pentacam; Oculus Optikgeräte GmbH, Wetzlar, Germany); the central corneal thickness (CCT) and corneal biomechanics were measured using a Corvis ST II (software version 1.6r2015, Oculus, Wetzlar, Germany). All the examinations were performed by the same investigator to eliminate possible interobserver variability.

Measurement of corneal biomechanical parameters

The corneal biomechanical properties were measured by a Corvis ST II, which has a highspeed Scheimpflug camera (4,330 f/s) that scans 8.0 mm horizontally and records 140 images. The Corvis ST II device measured the following parameters included dynamic corneal response parameters: first applanation time (A1T), first applanation length (A1L), first applanation velocity (A1V), second applanation time (A2T), second applanation length (A2L), second applanation velocity (A2V), highest concavity time (HCT), highest concavity peak distance (HC PD). It also provided the following biomechanical comparison display parameters: deformation amplitude ratio 2.0 mm (DA ratio 2.0 mm), integrated radius (IR), Ambrosio relational thickness to the horizontal profile (ARTh), and stiffness parameter A1 (SP-A1). Each measurement was taken three times to confirm the repeatability, and the best value was used for the further analysis. Only readings deemed by the system to be of "OK" quality were used in the analysis.

Statistical analysis

Statistical analyses were performed using IBM SPSS software (version 25.0; IBM/SPSS, Inc., Chicago, IL, USA). Mean ± standard deviation was used for quantitative variables. Data were tested for normality using the Shapiro-Wilk test. Group comparisons for normally distributed data were made using the paired *t* test. The Wilcoxon rank sum test and Wilcoxon signed rank test were used for non-normally distributed data. Linear regression analysis was performed to evaluate the relationship between CCT and CV and the biomechanical comparison display parameters (IR, SP-A1, ARTh, DA ratio 2.0 mm) postoperatively. P values less than 0.05 were considered statistically significant.

Results

Participants

In the present study, a total of 100 eyes of 50 patients with high myopia were included, with 50 eyes underwent SMILE and the contralateral eyes underwent FS-LASIK. The patients' demographic and preoperative baseline characteristics are presented in *Table 1*. The mean age of the participants was 25.59±4.92 years (range, 18 to 40 years); 12 (24%) patients were male, and 38 (76%) patients were female. The final follow-up visit ranged from 13 months to 20 months (the median follow-up time: 15 months). All surgeries were successfully performed with no observed complications. No significant differences were recorded in preoperative CCT, CV, or biomechanical corrected intraocular pressure (bIOP) between SMILE and FS-LASIK. A larger attempted lenticule thickness (LT) and a

Table 1 Demographic data and characteristics of patients

Parameter	SMILE (n=50)	FS-LASIK (n=50)	P
Age (y)	25.92±4.92 (18 to 40)	25.92±4.92 (18 to 40)	–
Sex (male/female)	12/38	12/38	–
MRSE (D)	−8.46±1.04 (−10.00 to −6.38)	−8.52±1.12 (−10.00 to −6.38)	0.159
Sphere (D)	−7.96±1.11 (−9.25 to −5.25)	−8.04±1.21 (−9.75 to −5.5)	0.062
Cylinder (D)	−1.03±0.69 (−2.50 to 0.00)	−0.98±0.71 (−2.75 to 0.00)	0.478
CCT (μm)	552.78±38.83 (503 to 697)	552.89±38.97 (499 to 683)	0.352
CV (mm^3)	62.34±3.97 (56.2 to 73.9)	62.25±3.99 (55.8 to 74.3)	0.654
Ablation zone (mm)	6.14±0.15 (6.0 to 6.8)	6.14±0.15 (6.0 to 6.8)	–
Maximum LT/AD (μm)	137.16±14.99 (100 to 166)	119.30±14.69 (88 to 148)	<0.001
RST (μm)	293.44±23.83 (270 to 397)	325.62±28.03 (295 to 439)	<0.001
bIOP (mmHg)	16.05±2.29 (11.7 to 29.2)	16.11±2.25 (12.2 to 27.6)	0.697

Data are shown as mean ± SD (range). SMILE, small incision lenticule extraction; FS-LASIK, femtosecond laser-assisted in situ keratomileusis; MRSE, manifest refraction spherical equivalent; D, Diopter; CCT, central corneal thickness; CV, corneal volume; LT, lenticule thickness; AD, ablation depth; RST, residual stromal thickness; bIOP, biomechanical corrected intraocular pressure.

lower residual stromal thickness (RST) were observed in SMILE than that in FS-LASIK (P<0.001).

Corneal biomechanical parameters

The corneal biomechanical parameters of SMILE and FS-LASIK pre- and postoperatively are shown in *Table 2*. The ARTh and SP-A1 were significantly larger in SMILE than in FS-LASIK at all the follow-up visits (all P<0.05). No significant differences in other biomechanical parameters were observed between the two groups. As shown in *Figure 1*, the ARTh and SP-A1 decreased significantly, whereas the DA ratio 2.0 mm and IR increased significantly after SMILE and FS-LASIK. In addition, the biomechanical comparison parameters were typically stable from 1 month to 15 months postoperatively.

Changes in the CCT and CV

The CCT and CV after SMILE and FS-LASIK during the follow-up visits are presented in *Figure 2*. The CCT in SMILE was greater than that in FS-LASIK at 15 months postoperatively (435.94±29.93 versus 425.65±30.33 μm; P<0.001). Likewise, the CV in SMILE was larger than that in FS-LASIK at all the follow-up visits (59.68±3.98 versus 59.03±4.04 mm^3; P<0.001).

Correlations between corneal biomechanical parameters and the CCT and CV

The scatterplots and results of simple linear regression between postoperative CCT, CV, and the biomechanical comparison display parameters (IR, SP-A1, ARTh, DA ratio 2.0 mm) are presented in *Figure 3*. The CCT was positively correlated with ARTh (the SMILE group: R^2=0.371, P<0.001; the FS-LASIK group: R^2=0.409, P<0.001) and SP-A1 (SMILE group: R^2=0.469, P<0.001; FS-LASIK group: R^2=0.361, P<0.001) but had a negative correlation with the IR (the SMILE group: R^2=0.292, P<0.001; the FS-LASIK group: R^2=0.329, P<0.001) and DA ratio 2.0 mm (the SMILE group: R^2=0.227, P=0.001; the FS-LASIK group: R^2=0.387, P<0.001). The CV had a moderately positive correlation with SP-A1(the SMILE group: R^2=0.297, P<0.001; the FS-LASIK group: R^2=0.284, P<0.001), whereas no significant correlation was found between CV and ARTh, IR, or DA ratio 2.0 mm.

Discussion

In the present study, a contralateral eye designed comparative study was conducted in patients with high myopia, which eliminated individual bias, as age and individual corneal responses are similar in the same individual. Moreover, we have evaluated the corneal

Table 2 Corneal biomechanics parameters preoperatively and postoperatively

Parameters	Preoperative			1 month			3 months			6 months			15 months		
	SMILE	FS-LASIK	Difference 95% CI	SMILE	FS-LASIK	Difference 95% CI	SMILE	FS-LASIK	Difference 95% CI	SMILE	FS-LASIK	Difference 95% CI	SMILE	FS-LASIK	Difference 95% CI
A1 time	7.65±0.36	7.63±0.36	0.02 (–0.04, 0.08)	7.18±0.22	7.17±0.24	0.01 (–0.03, 0.05)	7.12±0.19	7.11±0.17	0.008 (–0.032, 0.477)	7.09±0.19	7.12±0.20	–0.03 (–0.08, 0.02)	7.14±0.21	7.10±0.19	0.04 (–0.01, 0.08)
A1 length	2.14±0.34	2.14±0.36	–0.005 (–0.13, 0.12)	2.00±0.29	2.04±0.29	–0.04 (–0.13, 0.06)	1.95±0.21	1.97±0.29	–0.1 (–0.11, 0.09)	1.94±0.19	1.90±0.21	0.03 (–0.05, 0.11)	1.94±0.27	1.95±0.29	–0.01 (–0.13, 0.10)
A1 velocity	0.15±0.02	0.15±0.02	–0.001 (–0.004, 0.003)	0.15±0.02	0.15±0.02	–0.006 (–0.010, 0.001)	0.15±0.01	0.16±0.02	–0.008 (–0.012, 0.005)	0.15±0.01	0.16±0.01	–0.005 (–0.009, –0.001)	0.15±0.01	0.16±0.02	–0.004 (–0.008, 0.08)
A2 time	22.23±0.35	22.30±0.38	–0.06 (–0.15, 0.02)	22.11±2.92	22.58±0.43	–0.46 (–1.28, 0.35)	22.76±0.28	22.74±0.51	0.009 (–0.14, 0.16)	22.82±0.32	22.82±0.35	–0.003 (–0.09, 0.09)	22.81±0.31	22.84±0.32	–0.03 (–0.09, 0.04)
A2 length	2.09±0.50	2.03±0.40	0.05 (–0.11, 0.22)	1.54±0.44	1.55±0.47	–0.007 (–0.18, 0.17)	1.49±0.51	1.48±0.44	0.009 (–0.16, 0.18)	1.35±0.36	1.40±0.37	–0.05 (–0.20, 0.11)	1.50±0.38	1.59±0.42	–0.10 (–0.27, 0.08)
A2 velocity	–0.26±0.04	–0.26±0.03	–0.008 (–0.020, 0.003)	–0.26±0.05	–0.27±0.04	0.01 (–0.004, 0.024)	–0.31±0.26	–0.27±0.05	–0.04 (–0.12, 0.38)	–0.28±0.02	–0.28±0.03	–0.004 (–0.013, 0.004)	–0.27±0.03	–0.28±0.03	0.007 (–0.003, 0.02)
HC time	17.36±0.48	17.43±0.48	–0.07 (–0.27, 0.13)	17.43±0.49	17.41±0.53	0.02 (–0.17, 0.20)	17.53±0.52	17.46±0.50	0.07 (–0.14, 0.28)	17.38±0.43	17.38±0.96	–0.005 (–0.29, 0.28)	17.41±0.55	17.41±0.50	0.004 (–0.18, 0.19)
HC R	7.59±0.92	7.71±1.12	–0.12 (–0.44, 0.21)	6.10±0.43	6.04±0.49	0.06 (–0.11, 0.22)	6.18±0.43	6.09±0.62	0.09 (–0.10, 0.27)	6.13±0.38	6.05±0.39	0.08 (–0.02, 0.18)	6.14±0.53	6.10±0.48	–0.07 (–0.18, 0.04)
HC PD	5.05±0.30	5.09±0.30	–0.04 (–0.09, 0.02)	5.33±0.26	5.33±0.25	–0.005 (–0.05, 0.04)	5.40±0.16	5.43±0.23	–0.03 (–0.08, 0.03)	5.46±0.16	5.43±0.21	0.03 (–0.01, 0.08)	5.43±0.21	5.50±0.38	0.04 (–0. 13, 0.21)
DA ratio 2.0 mm	4.19±0.41	4.29±0.54	0.10 (–0.197, –0.003)	5.48±0.59	5.45±0.58	0.02 (–0.12, 0.17)	5.47±0.49	5.54±0.50	–0.06 (–0.18, 0.05)	5.57±0.82	5.49±0.48	0.93 (–2.96, 1.11)	5.46±0.45	5.54±0.52	–0.08 (–0.19,0.03)
IR	7.89±1.05	7.87±1.02	0.02 (–0.19, 0.23)	11.05±0.89	11.13±1.00	–0.08 (–0.26, 0.10)	11.18±0.64	11.25±0.78	–0.07 (–0.25, 0.10)	11.14±0.65	11.28±0.86	0.14 (–0.12, 0.30)	11.15±0.79	11.11±0.82	0.04 (–0.12, 0.20)
ARTh	538.49±94.68	525.63±99.28	8.85 (–20.58, 38.29)	119.41±13.27	110.05±14.31	9.37 (6.32, 12.42) ***	124.85±11.94	114.10±13.98	10.74 (7.88, 13.60)***	128.95±13.38	118.18±14.94	9.78 (6.27, 13.29) ***	133.15±18.64	123.23±16.39	9.78 (6.27, 13.29)***
SP-A1	117.67±22.31	114.62±17.16	3.07 (–1.92, 8.06)	84.76±21.11	79.49±22.41	5.26 (1.54, 8.99) **	81.85±16.96	74.82±20.29	7.03 (2.74, 11.31)**	81.27±15.56	76.64±16.48	4.62 (1.76, 7.49) **	81.14±18.25	77.03±17.21	4.11 (0.03, 8.19)*
CBI	0.10±0.19	0.11±0.19	–0.01(–0.03, 0.03)	0.01±0.07	0.02±0.05	–0.003 (–0.02, 0.01)	0.03±0.15	0.03±0.15	–0.002 (–0.06, 0.06)	0.03±0.12	0.05±0.18	–0.02 (–0.08, 0.04)	0.02±0.09	0.00±0.00	0.02 (–0.006, 0.04)
SSI	0.89±0.11	0.89±0.13	0.004 (–0.03,0.03)	0.94±0.19	0.98±0.33	–0.04 (–0.13, 0.04)	0.87±0.16	0.89±0.26	–0.02 (–0.10, 0.06)	0.83±0.09	0.90±0.28	–0.08 (–0.16, –0.008)	0.85±0.13	0.89±0.25	–0.04 (–0.11, –0.04)

Data are shown as mean ± SD. **P<0.01; ***P<0.001. Differences, mean values of SMILE-FS-LASIK. SMILE, small incision lenticule extraction; FS-LASIK, femtosecond laser-assisted in situ keratomileusis; CI, confidence interval; HC R, highest concavity radius; HC PD, highest concavity peak distance; DA ratio 2.0 mm, deformation amplitude ratio 2.0 mm; IR, integrated radius; ARTh, Ambrosio relational thickness through the horizontal meridian; SP-A1, stiffness parameter at first applanation; CBI, Corvis biomechanical index; SSI, corneal stress-strain index.

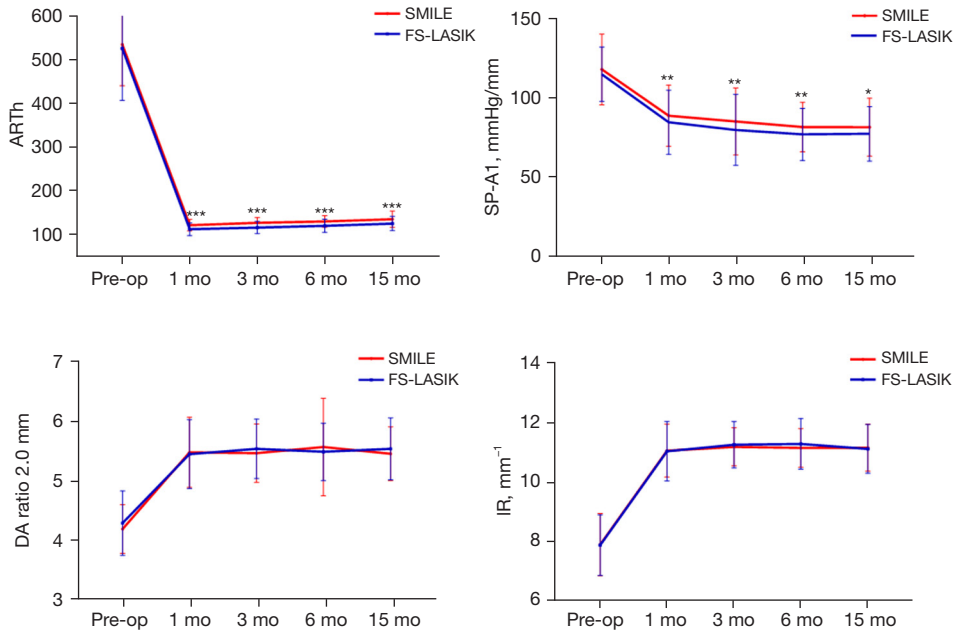

Figure 1 Changes in corneal biomechanical parameters after SMILE and FS-LASIK. **P<0.01, statistically significant; *P<0.05, statistically significant; ***P<0.001, statistically significant. ARTh, Ambrosio relational thickness to the horizontal profile; Pre-op, preoperative; mo, month; SMILE, small incision lenticule extraction; FS-LASIK, femtosecond laser-assisted in situ keratomileusis; SP-A1, stiffness parameter A1; DA, deformation amplitude; IR, integrated radius.

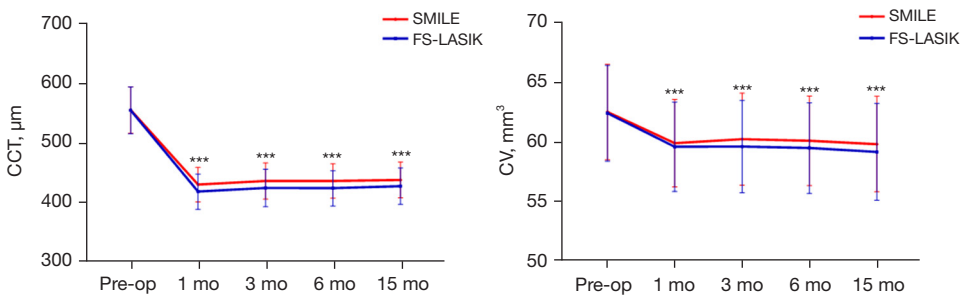

Figure 2 Changes in CCT and CV after SMILE and FS-LASIK. ***P<0.001, statistically significant. Pre-op, preoperative; mo, month; CCT, central corneal thickness; CV, corneal volume; SMILE, small incision lenticule extraction; FL-LASIK, femtosecond laser-assisted in situ keratomileusis.

biomechanics beyond 1 year postoperatively, which could suggest a good stability of our results. To the best of our knowledge, this is the first contralateral eye study to compare the changes in corneal biomechanics in patients with the same POZ and similar refractive correction after SMILE and FS-LASIK for high myopia *in vivo*. Our data showed that ARTh and SP-A1were larger after SMILE than that after FS-LASIK at all the follow-up visits. In addition, the significantly greater CCT and CV were found after SMILE than that after FS-LASIK.

Four important biomechanical display parameters were measured using the Corvis ST II. Our data showed significant decreases in ARTh and SP-A1 and increases in IR and DA ratio 2.0 mm after both SMILE and FS-LASIK. The SP-A1 is generated from the initial data acquired by the Corvis ST II, which has been regarded as an important parameter for assessing corneal stiffness (19). The larger the SP-A1 value is, the stiffer the cornea is. The ARTh is the quotient of corneal thickness at the thinnest point of the horizontal meridian and the thickness progression (20).

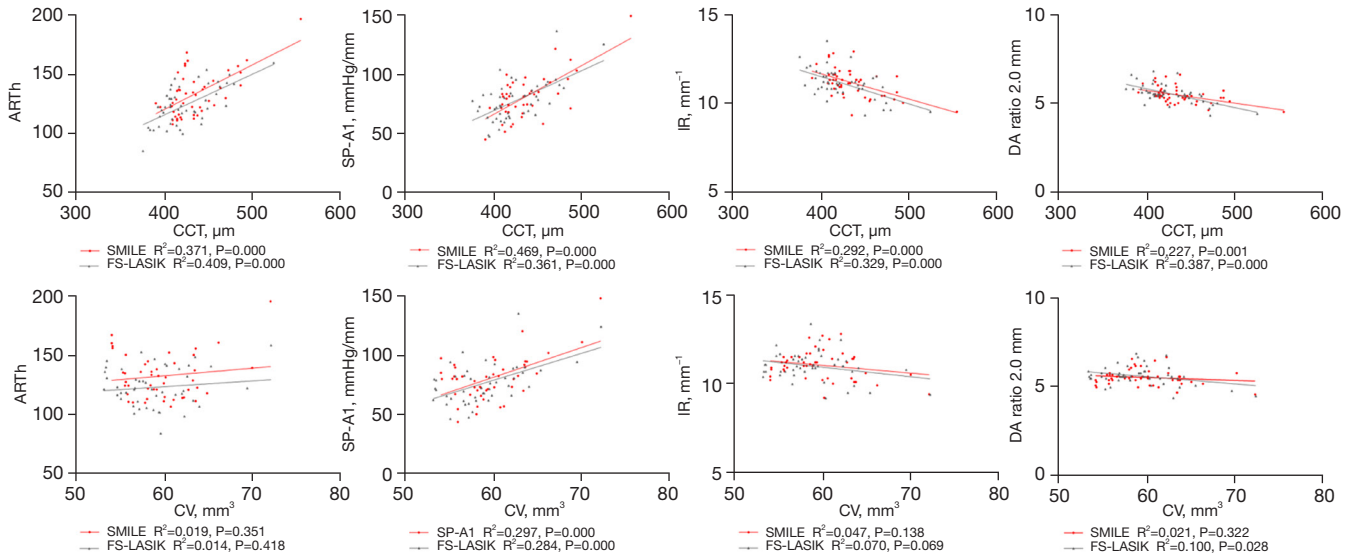

Figure 3 Scatterplots and simple linear regression analysis between corneal biomechanical parameters and CCT and CV postoperatively. ARTh, Ambrosio relational thickness to the horizontal profile; CCT, central corneal thickness; SMILE, small incision lenticule extraction; FS-LASIK, femtosecond laser-assisted in situ keratomileusis; SP-A1, stiffness parameter A1; IR, integrated radius; DA, deformation amplitude; CV, corneal volume.

A lower ARTh means a thinner cornea and a faster thickness progression toward the periphery. In the present study, SMILE yielded a larger ARTh and SP-A1 than did FS-LASIK postoperatively, which indicated the thicker and stiffer corneas after SMILE than that after FS-LASIK. This finding is consistent with what reported by Abd El-Fattah *et al.* (6). They demonstrated that there were significant differences in IR and SP-A1 between SMILE and FS-LASIK at 6 months after surgery using Corvis ST II, which suggested that there were better corneal biomechanics and stiffer corneas after SMILE. However, some previous studies revealed results that were inconsistent with those of our study (7,8). For example, Sefat *et al.* indicated no significant changes in biomechanical parameters measured by Corvis ST after SMILE and FS-LASIK (7). Another fellow eye study using an ocular response analyzer (ORA), the first designed for the *in vivo* measurement of corneal biomechanical properties, also showed no significant differences in corneal hysteresis (CH) and corneal resistance factor (CRF) between the two surgeries (8). To date, few of these studies have focused on evaluating patients with high myopia. The reason for the discrepancy in different studies might be explained by related to the different control designs, measurements of corneal biomechanics, and refractive correction.

Moreover, we have compared the postoperative CCT and CV between SMILE and FS-LASIK. In the present study, a significant decrease in the postoperative CCT and CV was found after SMILE and FS-LASIK due to corneal tissue removal. In addition, the postoperative CCT and CV after SMILE were greater than those after FS-LASIK, which suggested that the SMILE procedure could preserve more corneal tissue when correcting the similar refractive errors in patients with high myopia. Yang *et al.* also demonstrated that corneal thickness after SMILE was greater than that after FS-LASIK for high myopia (21). Several reasons could explain this phenomenon. First, the laser software underestimated the predicted ablation depth in eyes treated with FS-LASIK and overestimated corneal reduction in eyes treated with SMILE (22). Second, there were different wound healing processes after SMILE and FS-LASIK.

Furthermore, we have evaluated the correlations between corneal biomechanical parameters and CCT and CV. Our results indicated that postoperative CCT was positively correlated with ARTh and SP-A1 but negatively correlated with IR and DA ratio 2.0 mm, which was consistent with the previous studies (6,17). Notably, there was also a positive correlation between CV and SP-A1. The CV is an important parameter for reflecting the changes in the corneal tissue characteristics after surgery (23). This is the first study to find a correlation between CV and SP-A1.

Wei *et al.* have provided evidence of a positive relationship between CV and CH and CRF after SMILE and FS-LASIK using ORA (24). They attributed this phenomenon to a thicker cornea containing more collagen fibers and ground substance, which resulted in a greater resistance against deformation and a higher damping capacity. Hence, we could hypothesize that SMILE created relatively better biomechanics, which was partly related to the greater postoperative CCT and CV after SMILE for high myopia. This hypothesis was confirmed using the simple linear regression analysis, which showed that the CCT and the CV were positively correlated with SP-A1.

One limitation of this study is that the cap and flap thickness was different after SMILE and FS-LASIK, on account of considering the safe RST after FS-LASIK. Some previous studies also designed different cap and flap in SMILE and FS-LASIK (6,16) and they demonstrated that there were no differences in corneal biomechanics between SMILE and FS-LASIK. However, to confirm whether different cap and flap would significantly affect corneal biomechanics, further larger-sample studies are needed.

In conclusion, in this contralateral eye study, our data showed that there were larger ARTh and SP-A1 in SMILE compared with FS-LASIK in patients with high myopia. Moreover, the CCT and CV in SMILE were greater than those in FS-LASIK. We demonstrated that SMILE could yield relatively less influence on corneal biomechanics in high myopia cases with the similar refractive correction and the same POZ. Our results could not only demonstrate more accurate conclusions of the comparison of corneal biomechanics between SMILE and FS-LASIK, but also provide evidence for the appropriate choice of surgery in patients with high myopia.

Acknowledgments

We gratefully acknowledge Editors at Cactus Communications and AJE for English language editing.
Funding: This study was supported by the National Natural Science Foundation of China (Grant No. 81900850 and 82101134), the Science and Technology Planning Projects of Guangzhou city (No. 201803010091 and 201804010076), and the Science and Technology Project of Guangzhou (No. 2018A030313573).

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-330/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-330/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-330/coif). All authors report that this study was supported by the National Natural Science Foundation of China (Grant Nos. 81900850 and 82101134), the Science and Technology Planning Projects of Guangzhou city (Nos. 201803010091 and 201804010076), and the Science and Technology Project of Guangzhou (No. 2018A030313573). The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in agreement with the tenets of the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Board of the Zhongshan Ophthalmic Center of Sun Yat-sen University (Identifier No. 2020KYPJ159). The informed written consent was obtained from all participants.

References

1. Vestergaard A, Ivarsen AR, Asp S, et al. Small-incision lenticule extraction for moderate to high myopia: Predictability, safety, and patient satisfaction. J Cataract Refract Surg 2012;38:2003-10.
2. Lau YT, Shih KC, Tse RH, et al. Comparison of Visual, Refractive and Ocular Surface Outcomes Between Small Incision Lenticule Extraction and Laser-Assisted In Situ Keratomileusis for Myopia and Myopic Astigmatism.

Ophthalmol Ther 2019;8:373-86.
3. Sinha Roy A, Dupps WJ Jr, Roberts CJ. Comparison of biomechanical effects of small-incision lenticule extraction and laser in situ keratomileusis: finite-element analysis. J Cataract Refract Surg 2014;40:971-80.
4. Spiru B, Kling S, Hafezi F, et al. Biomechanical Properties of Human Cornea Tested by Two-Dimensional Extensiometry Ex Vivo in Fellow Eyes: Femtosecond Laser-Assisted LASIK Versus SMILE. J Refract Surg 2018;34:419-23.
5. Wang D, Liu M, Chen Y, et al. Differences in the corneal biomechanical changes after SMILE and LASIK. J Refract Surg 2014;30:702-7.
6. Abd El-Fattah EA, El Dorghamy AA, Ghoneim AM, et al. Comparison of corneal biomechanical changes after LASIK and F-SMILE with CorVis ST. Eur J Ophthalmol 2021;31:1762-70.
7. Sefat SM, Wiltfang R, Bechmann M, et al. Evaluation of Changes in Human Corneas After Femtosecond Laser-Assisted LASIK and Small-Incision Lenticule Extraction (SMILE) Using Non-Contact Tonometry and Ultra-High-Speed Camera (Corvis ST). Curr Eye Res 2016;41:917-22.
8. Agca A, Ozgurhan EB, Demirok A, et al. Comparison of corneal hysteresis and corneal resistance factor after small incision lenticule extraction and femtosecond laser-assisted LASIK: a prospective fellow eye study. Cont Lens Anterior Eye 2014;37:77-80.
9. Leccisotti A. Corneal ectasia after photorefractive keratectomy. Graefes Arch Clin Exp Ophthalmol 2007;245:869-75.
10. Binder PS. Analysis of ectasia after laser in situ keratomileusis: risk factors. J Cataract Refract Surg 2007;33:1530-8.
11. Hong J, Xu J, Wei A, et al. A new tonometer--the Corvis ST tonometer: clinical comparison with noncontact and Goldmann applanation tonometers. Invest Ophthalmol Vis Sci 2013;54:659-65.
12. Shen Y, Zhao J, Yao P, et al. Changes in corneal deformation parameters after lenticule creation and extraction during small incision lenticule extraction (SMILE) procedure. PLoS One 2014;9:e103893.
13. Vinciguerra R, Ambrósio R Jr, Elsheikh A, et al. Detection of Keratoconus With a New Biomechanical Index. J Refract Surg 2016;32:803-10.
14. Lee R, Chang RT, Wong IY, et al. Assessment of corneal biomechanical parameters in myopes and emmetropes using the Corvis ST. Clin Exp Optom 2016;99:157-62.
15. Han F, Li M, Wei P, et al. Effect of biomechanical properties on myopia: a study of new corneal biomechanical parameters. BMC Ophthalmol 2020;20:459.
16. Cao K, Liu L, Yu T, et al. Changes in corneal biomechanics during small-incision lenticule extraction (SMILE) and femtosecond-assisted laser in situ keratomileusis (FS-LASIK). Lasers Med Sci 2020;35:599-609.
17. Liu M, Shi W, Liu X, et al. Postoperative corneal biomechanics and influencing factors during femtosecond-assisted laser in situ keratomileusis (FS-LASIK) and laser-assisted subepithelial keratomileusis (LASEK) for high myopia. Lasers Med Sci 2021;36:1709-17.
18. Lee H, Roberts CJ, Kim TI, et al. Changes in biomechanically corrected intraocular pressure and dynamic corneal response parameters before and after transepithelial photorefractive keratectomy and femtosecond laser-assisted laser in situ keratomileusis. J Cataract Refract Surg 2017;43:1495-503.
19. Roberts CJ, Mahmoud AM, Bons JP, et al. Introduction of Two Novel Stiffness Parameters and Interpretation of Air Puff-Induced Biomechanical Deformation Parameters With a Dynamic Scheimpflug Analyzer. J Refract Surg 2017;33:266-73.
20. Lopes BT, Ramos I de C, Salomão MQ, et al. Horizontal pachymetric profile for the detection of keratoconus. Revista Brasileira de Oftalmologia 2015;74:382-5.
21. Yang X, Liu Q, Liu F, et al. Comparison of outcome between small incision lenticule extraction and FS-LASIK in eyes having refractive error greater than negative 10 diopters. J Cataract Refract Surg 2020;46:63-71.
22. Zisimopoulos A, Vingopoulos F, Kanellopoulos AJ. Comparison of Planned Versus Achieved Central Stromal Thickness Reduction in LASIK Versus SMILE: A Contralateral Eye Study. J Refract Surg 2021;37:454-9.
23. Suzuki H, Takahashi H, Hori J, et al. Phacoemulsification associated corneal damage evaluated by corneal volume. Am J Ophthalmol 2006;142:525-8.
24. Wei P, Cheng GP, Zhang J, et al. Changes in Corneal Volume at Different Areas and Its Correlation with Corneal Biomechanics after SMILE and FS-LASIK Surgery. J Ophthalmol 2020;2020:1713979.

Cite this article as: He S, Luo Y, Ye Y, Chen P, Liu C, Lei L, Zhuang J, Yu K. A comparative and prospective study of corneal biomechanics after SMILE and FS-LASIK performed on the contralateral eyes of high myopia patients. Ann Transl Med 2022;10(13):730. doi: 10.21037/atm-22-330

