· Clinical Research ·

Changes in posterior corneal elevation after small incision lenticule extraction for different myopic diopters

Xiao-Tong Sun, Yang Zhang, Xiao-Kun Mei, Nan-Nan Zheng, Ling-Zhi Niu, Xiao-Li Qu, Ai-Ping Song, Jian Zhuo

Department of Ophthalmology, the First Affiliated Hospital of Shandong First Medical University, Shandong Provincial Qianfoshan Hospital, Jinan 250014, Shandong Province, China

Correspondence to: Ai-Ping Song and Jian Zhuo. Department of Ophthalmology, the First Affiliated Hospital of Shandong First Medical University, Shandong Provincial Qianfoshan Hospital, 16766# Jingshi Road, Jinan 250014, Shandong Province, China. 13793164931@163.com; 1151385662@qq.com

Received: 2023-07-24 Accepted: 2023-11-28

Abstract

● **AIM:** To study the changes and effect factors of posterior corneal surface after small incision lenticule extraction (SMILE) with different myopic diopters.

● **METHODS:** Ninety eyes of 90 patients who underwent SMILE were included in this retrospective study. Patients were allocated into three groups based on the preoperative spherical equivalent (SE): low myopia (SE≥-3.00 D), moderate myopia (-3.00 D>SE>-6.00 D) and high myopia (SE≤-6.00 D). Posterior corneal surfaces were measured by a Scheimpflug camera preoperatively and different postoperative times (1wk, 1, 3, 6mo, and 1y). Posterior mean elevation (PME) at 25 predetermined points of 3 concentric circles (2-, 4-, and 6-mm diameter) above the best fit sphere was analyzed.

● **RESULTS:** All surgeries were completed uneventfully and no ectasia was found through the observation. The difference of myopia group was significant at the 2-mm ring at 1 and 3mo postoperatively (1mo: P=0.017; 3mo: P=0.018). The effect of time on ΔPME was statistically significant (2-mm ring: P=0.001; 4-mm ring: P<0.001; 6-mm ring: P<0.001). The effect of different corneal locations on ΔPME was significant except 1wk postoperatively (1mo: P=0.000; 3mo: P=0.000; 6mo: P=0.001; 1y: P=0.001). Posterior corneal stability was linearly correlated with SE, central corneal thickness, ablation depth, residual bed thickness, percent ablation depth and percent stromal bed thickness.

● **CONCLUSION:** The posterior corneal surface changes dynamically after SMILE. No protrusion is observed on the posterior corneal surface in patients with different degrees of myopia within one year after surgery. SMILE has good stability, accuracy, safety and predictability.

● **KEYWORDS:** myopia; posterior corneal elevation; corneal ectasia; small incision lenticule extraction

DOI:10.18240/ijo.2024.03.11

Citation: Sun XT, Zhang Y, Mei XK, Zheng NN, Niu LZ, Qu XL, Song AP, Zhuo J. Changes in posterior corneal elevation after small incision lenticule extraction for different myopic diopters. *Int J Ophthalmol* 2024;17(3):491-498

INTRODUCTION

Small incision lenticule extraction (SMILE) has become the mainstream surgical method of refractive surgery. SMILE surgery has the following advantages: non-flap, minimally invasive, high accuracy, good refractive stability after surgery, fewer complications and so on. SMILE is a valveless procedure that has less impact on corneal biomechanics[1-2]. However, corneal dilation is still proved to exist after SMILE surgery[3]. Corneal dilatation is one of the most serious complications after refractive surgery, so the evaluation of corneal biomechanical changes after SMILE is a hot topic of research.

The operation of SMILE surgery is limited to the anterior surface of the cornea, and the posterior surface is almost not affected by the procedure and healing process. Therefore, the morphological changes of the posterior corneal surface after the surgery are great valued for the long-term efficacy monitoring and safety evaluation of the surgery. Compared with curvature data, posterior corneal surface information is not affected by direction, position, and tear film, so it can more accurately characterizes the morphological changes of the posterior corneal surface. Previous researches had shown that the changes in posterior surface height after laser *in situ* keratomelusis (LASIK) were influenced by corneal thickness and laser ablation depth (AD)[4-5]. Risk factors for corneal dilatation after SMILE surgery remain unclear. Previous reports also had evaluated the safety and effectiveness of SMILE surgery by preoperative and postoperative uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), spherical equivalent (SE), acular axial length (AL), and subjective visual quality[6-7]. However, we believe that posterior corneal elevation is the most effective and objective parameter for identifying early dilatation changes[8-9]. In this study, we used the latest generation Scheimpfulg camera (PentacamOculus Optikgerate GmbH, Wetzlar, Germany) to follow up the posterior corneal surface height in different areas with different degrees of myopia. The purpose of this study is to evaluate the safety and stability of SMILE surgery and to explore the risk factors of corneal dilatation after SMILE surgery.

SUBJECTS AND METHODS

Ethical Approval This retrospective study complied with the tenets of the Declaration of Helsinki. This study was approved by the Ethics Committee of the First Affiliated Hospital of Shandong First Medical University (approval number: S400). All participants provided written informed consent prior to the initiation of the study sessions.

Subjects The retrospective clinical observational study recruited 90 eyes of 90 patients undergoing SMILE at the Department of Ophthalmology, the first Affiliated Hospital of Shandong First Medical University from January 2020 to December 2021.

Inclusion Criteria 1) Between 18 and 35 years of age; 2) The degree of SE was between -1.00 and -9.00 D, and the degree of astigmatism was between 0 and -5.00 D; 3) The preoperative best corrected visual acuity was ≥1.0; 4) The diopter of the operated eyes was stable in the past two years, or the increase was not more than 0.5 D per year; 5) Contact lens wear was stopped for at least 2wk for soft contact lenses and for at least 3wk for hard contact lenses, or there was clear evidence that the corneal morphology had stabilized. The evidences included the consistency of two consecutive comprehensive optometry data, central corneal thickness (CCT), anterior surface curvature of the topography, anterior surface height, and anterior surface astigmatism.

Exclusion Criteria 1) Patients were diagnosed as subclinical or clinical keratoconus before surgery; 2) Thin cornea (CCT<480 μm) or expected residual stromal bed thickness after lenticule extraction <250 μm; 3) Patients with corneal opacity such as corneal cloudiness or macula; 4) Patients with severe dry eye, corneal degeneration, glaucoma, fundus disease and other ocular diseases; 5) Patients with diabetes mellitus, connective tissue disease, or other systemic diseases.

Methods All patients underwent uncorrected and corrected visual acuity, refraction, non-contact intraocular pressure measurement, anterior tomography (PentacamOculus Optikgerate GmbH, Wetzlar, Germany) and slit lamp examination preoperatively and at 1wk, 1, 3, 6mo, and 1y postoperatively.

All surgeries were performed by an experienced ophthalmologist using a VisuMax3.0 femtosecond laser system (Carl Zeiss Meditec AG, Germany). First, the operative eye was placed under a curved contact lens after surface anesthesia, and the doctor instructed the patient to fix the internal flashing fixation light. Second, the surgeon confirmed correct fixation and corneal vertex alignment and initiated negative pressure suction, followed by femtosecond laser scanning. Finally, the surgeon separated the anterior and posterior interface of the corneal stromal lens with a corneal stromal lens separator and then removed the corneal stromal lens after the laser scanning was completed. The femtosecond laser was set as follows: pulse energy of 130 nJ, frequency of 500 kHz, corneal cap thickness of 110-130 μm, optical region of 6.0-6.5 mm (lens diameter), corneal cap diameter of 7.3-7.5 mm, and edge incision of 2 mm (45°) at 120 degrees. The patient was instructed to administer 0.05% levofloxacin eye drops and 0.1% flumiron eye drops postoperatively.

The 25 predetermined points corresponding to the preoperative best fit sphere were measured from Scheimpflug camera (PentacamOculus Optikgerate GmbH, Wetzlar, Germany). The 25 points were distributed on the vertex and the semi-meridian of 3 concentric circles (2-, 4-, and 6-mm diameter) along 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. We calculated posterior mean elevation (PME) for the 25 predetermined points. The height on each concentric circle was defined as PME2 (8 points on the circle 1 mm from the center plus vertices), PME4 (8 points each on the 1 and 2 mm rings from the center plus vertices), and PME6 (8 points each on the 1, 2, and 3 mm rings from the center plus vertices). The preoperative 8 mm corneal central zone best fit sphere was defined as a consistent reference plane for each pair of eyes (pre/postoperative). Data were recorded on an Excel spreadsheet (Microsoft Corp, Redmond, WA, USA) for further analysis. ΔPME was defined by subtracing preoperative data from postoperative data. Positive elevated values indicated forward movement of the posterior cornea, while negative elevated values indicated backward movement of the posterior cornea. We only analyzed results for which the check window showed "OK". If the check did not meet the requirements (marked by yellow or red), the check was repeated. Only corneal topography data with a valid measurement diameter of at least 8 mm was accepted.

Statistical Analysis All data were tested with Kolmogorov-Smirnov normality and homogeneity of variance and described by mean±standard error. Repeated measurement analysis of variance (ANOVA) was used to compare the ΔPME at different time points between the three groups. Spherical test hypothesis was adopted. If the spherical hypothesis test was not met, Roy's maximum root method was used for correction. Bivariate normal analysis was performed before correlation analysis, and then Pearson correlation was used to determine the relationship between ΔPME and related parameters. Statistical analysis was performed using SPSS ver.25.0 (SPSS Inc, Chicago, IL, USA). $P<0.05$ was considered statistically significant.

RESULTS

A total of 90 eyes of 90 subjects (52 males and 38 females) were enrolled. According to the preoperative SE, the patients were divided into low myopia group (30 eyes; range, -4.00 to -2.00 D; mean -2.79±0.58 D), moderate myopia group (30 eyes; range, -6.00 to -4.00 D; mean -4.67±0.37 D) and high myopia group (30 eyes; range, -6.25 to -8.25 D; mean -6.46±0.74 D). Demographic and preoperative clinical data of the patients were presented in Table 1.

The effect of myopia group on ΔPME was shown in Table 2, Figure 1. The difference of myopia group was significant at the 2-mm ring at 1 and 3mo postoperatively (1mo: P=0.017; 3mo: P=0.018). The posterior corneal surface was shifted backwards in the low and moderate myopia groups, while the high myopia group shifted forwards. Significant differences were found between the high myopia group and low myopia group, the high myopia group and moderate myopia group (1mo: P=0.0031, P=0.007, respectively; 3mo: P=0.012, P=0.016, respectively).

The effect of time on ΔPME was statistically significant (2-mm ring: P=0.001; 4-mm ring: P<0.001; 6-mm ring: P<0.001; Table 3, Figure 2A). At the 2-mm ring, the movement of the posterior corneal surface at different time points after surgery was manifested as: forward, backward, slightly forward, and back to the baseline level. The results of the pairwise comparison showed that the difference between 1wk postoperatively and other time points was statistically significant (1wk-1mo: P=0.000, 1wk-3mo: P=0.005, 1wk-6mo: P=0.000, 1wk-1y: P=0.000, respectively). At the 4-mm ring, the posterior corneal surface was shifted forwards at different time points. The maximum amount of forward movement occurred 1wk after surgery (0.58±1.16 μm). Posterior corneal surface height values fell back to baseline over time. At the 6-mm ring, the posterior corneal surface was shifted forwards at different time points. The largest amount occurred at 3mo postoperatively (0.72±0.74 μm). The amount gradually decreased over time, reaching 0.44±0.71 μm 1y after surgery.

The effect of different corneal locations on ΔPME was significant except 1wk postoperatively (1mo: P=0.000; 3mo: P=0.000; 6mo: P=0.001; 1y: P=0.001; Table 3, Figure 2B). At 1mo postoperatively, the posterior corneal surface of the 2-mm ring was shifted backwards and the rest shifted forwards. The amount of the 6-mm ring reached 0.53±0.83 μm. The results of the pairwise comparison showed that the difference between the 6-mm ring and other locations was statistically significant.

Table 1 Patient demographic information of low myopia, moderate myopia and high myopia

Items	Low myopia	Moderate myopia	High myopia
Age (y)			
Mean±SD	23.27±2.65	23.53±3.08	25.00±2.91
Range	19, 27	19, 30	21, 31
Preoperative SE (D)			
Mean±SD	-2.79±0.58	-4.67±0.37	-6.46±0.74
Range	-4.00, -2.00	-6.00, -4.00	-8.25, -6.25
Preperative CCT (μm)			
Mean±SD	559.40±21.61	559.90±31.46	555.00±28.86
Range	510, 590	508, 617	511, 608
AD (μm)			
Mean±SD	83.10±7.85	101.33±8.76	117.53±13.24
Range	72, 97	85, 117	75, 137
RBT (μm)			
Mean±SD	351.63±18.14	340.57±23.80	320.80±18.93
Range	321, 380	305, 392	295, 371

SE: Spherical equivalent; CCT: Central corneal thickness; AD: Ablation depth; RBT: Residual bed thickness.

Three months after surgery, the cornea in different positions showed forward movement. From the center to the periphery, the value of the forward movement gradually increased, and the 6-mm ring reached 0.72±0.74 μm. The differences between the groups were statistically significant. At 6mo and 1y after surgery, the trend of posterior corneal surface movement was similar at different locations. The posterior corneal surface of the 2-mm ring was shifted backwards and the rest of the position shifted forwards. The results of the pairwise comparison showed that the difference between the 2-mm ring and other locations was statistically significant.

Spearman correlation analysis was used to analyze the correlation between ΔPME and preoperative SE, preoperative CCT, AD, residual bed thickness (RBT), percent AD (PAD) and percent stromal bed thickness (PSBT). There was positive correlation between ΔPME and preoperative CCT, AD and PAD. There was negtive correlation between ΔPME and preoperative SE, RBT and PSBT (Figure 3).

DISCUSSION

As a novel minimally invasive new surgical method, SMILE has become the most mainstream surgical method for refractive error correction. SMILE has the advantages of small incision, high instantaneous power, low thermal effect, accurate cutting of corneal tissue and less damage. Compared with other surgical methods based on corneal flap, SMILE preserves the integrity of corneal tissue structure as much as possible. Since the SMILE procedure preserves the most stretch-resistant anterior stromal layer, it can greatly maintain the stability of the physiological morphological function of the cornea after surgery[10]. It has been reported that SMILE is more stable, predictable, safe and effective than other surgical procedures[10-11], but much of them are focused on short-

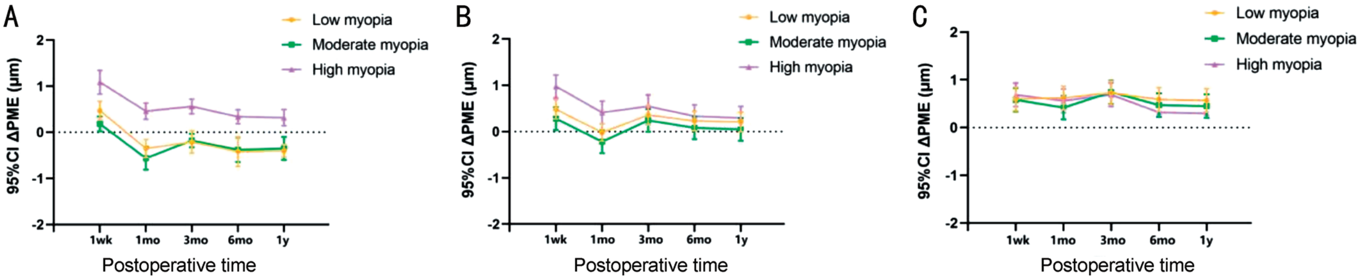

Figure 1 Posterior corneal elevation changes in different myopia groups A: ΔPME in different myopia groups at the 2 mm ring; B: ΔPME in different myopia groups at the 4-mm ring; C: ΔPME in different myopia groups at the 6-mm ring. PME: Posterior mean elevation.

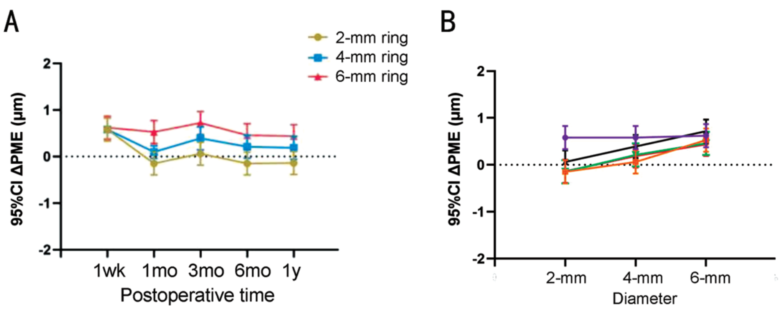

Figure 2 Elevation changes at the different locations of the cornea over time A: ΔPME at different time points; B: ΔPME at different corneal locations. PME: Posterior mean elevation.

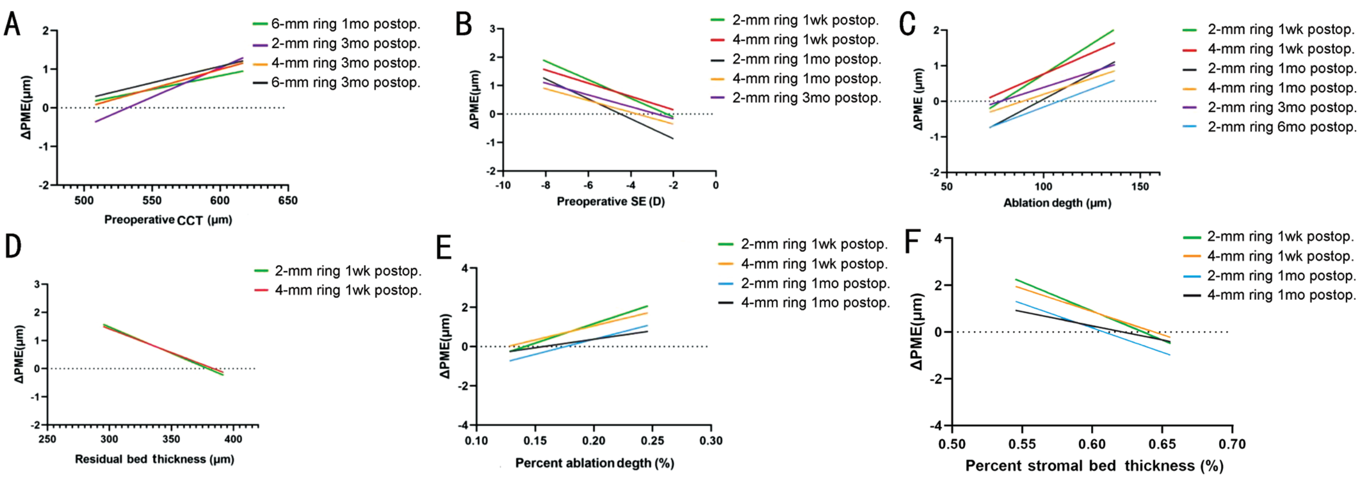

Figure 3 Linear regression analyses of the correlations between posterior corneal elevation changes and baseline parameters A: The correlations between ΔPME and preoperative CCT. B: The correlations between ΔPME and preoperative SE. C: The correlations between ΔPME and preoperative AD. D: The correlations between ΔPME and preoperative RBT. E: The correlations between ΔPME and preoperative PAD. F: The correlations between ΔPME and preoperative PSBT. PME: Posterior mean elevation; CCT: Central corneal thickness; SE: Spherical equivalent; AD: Ablation depth; RBT Residual bed thickness; PAD: Percent ablation depth; PSBT: Percent stromal bed thickness.

Table 2 Posterior corneal elevation after SMILE in different myopia groups

Time point	2-mm ring			*P*	4-mm ring			*P*	6-mm ring			*P*
	Low myopia	Moderate myopia	High myopia		Low myopia	Moderate myopia	High myopia		Low myopia	Moderate myopia	High myopia	
1wk	0.47±1.68	0.18±1.66	1.09±1.24	0.071	0.48±1.30	0.28±1.23	0.98±0.79	0.054	0.60±1.00	0.58±0.91	0.69±0.57	0.861
1mo	-0.34±1.42	-0.56±1.55	0.46±1.31	0.017	-0.02±1.08	-0.21±1.23	0.41±0.93	0.081	0.62±0.86	0.42±0.78	0.56±0.88	0.652
3mo	-0.21±1.06	-0.18±1.39	0.57±1.05	0.018	0.36±0.73	0.24±0.91	0.55±0.88	0.372	0.73±0.73	0.74±0.83	0.69±0.68	0.965
6mo	-0.42±1.29	-0.38±1.58	0.34±1.37	0.070	0.23±0.94	0.08±1.13	0.33±0.88	0.613	0.59±0.80	0.47±0.69	0.32±0.72	0.364
1y	-0.40±1.21	-0.35±1.47	0.32±1.34	0.073	0.21±0.92	0.05±1.09	0.30±0.84	0.589	0.57±0.78	0.45±0.65	0.30±0.70	0.337

SMILE: Small incision lenticule extraction.

term studies[12-13]. There are still cases of corneal ectasia after SMILE[3]. Notably, corneal dilation after SMILE can occur even in younger patients with normal preoperative corneal topography[14]. Therefore, evaluating the stability of refractive status after SMILE and the predictability of refractive effect is still a hot topic for clinicians.

Table 3 Changes in posterior mean elevation (ΔPME) in different corneal location at different follow-ups

Items	Time point					*P*
	1wk postop.	1mo postop.	3mo postop.	6mo postop.	1y postop.	
2-mm ring	0.58±1.57	-0.15±1.48	0.06±1.22	-0.15±1.44	-0.14±1.36	0.001
4-mm ring	0.58±1.16	0.06±1.11	0.39±0.84	0.21±0.98	0.19±0.95	0.000
6-mm ring	0.62±0.84	0.53±0.83	0.72±0.74	0.46±0.74	0.44±0.71	0.000
P	0.961	0.000	0.000	0.001	0.001	-
2-4 mm	-	0.249	0.023	0.026	0.036	-
2-6 mm	-	0.000	0.000	0.000	0.000	-
4-6 mm	-	0.007	0.020	0.130	0.103	-

Postop.: Postoparetively.

The posterior corneal surface is less disturbed by the external environment, and is not affected by the surgical operation and the healing process of corneal tissue after surgery. Therefore, most scholars believe that the changes in the posterior corneal surface height can be used as an important index to detect corneal ectasia and iatrogenic keratoconus after corneal refractive surgery[8]. According to the 2019 global expert consensus on keratoconus and corneal ectasia[15], the key point for the diagnosis of mild or subclinical keratoconus was abnormal elevation of the posterior cornral surface. With the rapid development of medical technology, the Pentacam anterior segment analyzer has been widely used in diagnosing ophthalmic diseases[16]. The Pentacam anterior segment analyzer adopts Scheimpflug optical imaging principle, and acquires 25 Scheimpflug sectional images of the whole cornea by 360 degree rotation scanning. Pentacam anterior segment analyzer can obtain the original height data of the cornea and accurately measure various parameters such as anterior and posterior surface curvature, anterior and posterior surface height, and corneal thickness, which is an important detection tool for corneal safety evaluation after refractive surgery[17]. However, most of the previous studies used Orbscan system, and its reliability was questioned. It has been reported that Orbscan overestimated the posterior corneal surface height of eyes undergoing corneal laser surgery[18]. Therefore, it is more meaningful to use the latest generation Pentacam anterior segment analyzer to measure the height of the posterior corneal surface at different times and different positions after SMILE surgery. The aim was to evaluate the risk of corneal dilatation and subclinical keratoconus after SMILE surgery, which also provides theoretical support for the evaluation of the safety and stability of SMILE surgery.

Corneal wound healing and remodeling changes continuously over time. At present, the results on the changes of posterior corneal surface height at different times after refractive surgery were different. Wang and Liao[19] studied the changes in the posterior corneal elevation after femtoseeond laser assisted laser *in situ* keratomileusis (FS-LASIK) and sub-Bowman keratomileusis (SBK) and found the maximum change occurred 1wk after surgery. Xu *et al*[20] found that the maximum change of posterior corneal elevation occurred 1wk after SMILE. The central area shifted backwards and the peripheral area shifted forwards. In contrast, Yu *et al*[21] showed that the maximum change occurred 1d after SMILE, and then tended to be stable and recovered to the preoperative state. In this study, the observation range was finely divided into three categories: central area (2-mm diameter ring), para-central area (4-mm diameter ring), and peripheral area (6-mm diameter ring), which made up for the shortcomings of previous studies. The time of postoperative observation was finely divided into early stage (1wk and 1mo), middle stage (3 and 6mo), and late stage (1y). Except for 6-mm ring, the maximum change of posterior corneal surface ocurred 1wk after surgery. The observed positions showed forward movement, tended to fall back to the preoperative position at 1mo after surgery except for 2-mm ring. We considered that the reasons for this result were related to inflammatory reaction and wound remodeling. One week after SMILE, edema of the central cornea, disorganized collagen fibers, and significant gaps between the corneal stroma appeared[22]. The corneal edema almost subsided and the collagen fibers were neatly arranged one month after surgery. Animal experiments by Wei *et al*[23] also confirmed that corneal collagen fibers were well preserved 1d after surgery, and potential gaps in the stromal layer could be observed one month after surgery. The animal experiment results provided the theoretical support for us. With the extension of time, the value of posterior corneal elevation approached baseline 6mo after surgery, and basically stabilized 6mo to 1y later. Previous studies had shown that the wound healing process after refractive surgery could last for up to 6mo, during which epithelial thickening and cellular fibrous interstitial scarring occurred[24]. In this study, the posterior corneal elevation showed dynamic fluctuations during the 1-year follow-up period. Byun *et al*[18] observed the posterior corneal surface height after epi-laser *in situ* keratomileusis (epi-LASIK), and the results showed that the height change was 2.08±2.29 μm. Our results showed a maximum movement of 1.09±1.24 μm at the posterior surface height, and we considered this small difference not to be evidence of corneal prominence. Therefore, we can reasonably conclude that the posterior surface height shows dynamic fluctuations but no significant lordosis during the 1-year follow-up period.

In this study, posterior surface height was analyzed in patients with different diopters. Our aim is to assess the safety of SMILE surgery at different diopters. The statistical results showed that the trend of posterior surface height change at different follow-up time points was basically the same between the low and moderate myopia groups. One week after surgery, the central area (2-mm ring), the paracentral area (4-mm ring) and the peripheral area showed anteriorization. The morphology of the posterior surface of the cornea is mainly affected by two forces: the corneal tension, which drives the lordosis or tendency to dilate the cornea, and the other tension, which is used to counteract the intraocular pressure. After the microlens was separated from the central stromal layer, the corneal resistance to tension was relatively decreased, so the surface of the cornea moved forward 1wk after surgery. After 3mo, the central cornea (2-mm ring) moved backward, the paracentral cornea (4-mm ring) moved forward slightly. But the peripheral area (6-mm ring) moved forward at all time points, to a greater extent than the paracentral area, and then recovered to the preoperative position and tended to be stable. Researchers proposed that hyperopic shift model could explain this phenomenon[25-26]. After refractive surgery, the wound in different areas was gradually remodeled. The central stromal cornea was cut, and the uncut peripheral matrix became relaxed, so that the tension was redistributed, resulting in flattening of the central zone and steepening of the peripheral area. This difference in different areas was also confirmed after LASIK[24]. However, some scholars[27] believed that it was unclear whether keratinocyte proliferation, tissue remodeling and other postoperative tissue reactions had an impact on the accuracy of Pentacam measurement, which should not be ignored. All the regions in the high myopia group moved forward, and the elevation was the largest 1wk after surgery. With the extension of postoperative follow-up time, the elevation gradually fell back to the baseline, and the height remained basically unchanged from 6mo to 1y after surgery. Because more stroma layers need to be cut in high myopia, the ablation of a large number of central stroma resulted in the destruction of corneal biomechanics and a significant decrease in low-to-moderate tension, so the high myopia group showed forward movement in all ranges. From the trend chart (Figure 1), it could be seen that the elevation gradually decreased from the central to the periphery in the early postoperative period, and stabilized in the postoperative 6mo. After removing the microlens, the tensile strength of the cornea in the peripheral area was significantly higher than that of the central cornea, so the central region had a greater forward compensation ability than the peripheral area[28]. The results showed that the central region advance was greater in the high myopia group, with a maximum value of 1.09±1.24 μm. Smile surgery with high myopia carried a certain risk of corneal instability. Patients with high myopia should be cautious when choosing SMILE surgery.

Our results showed that the posterior cornea exhibits regional dependence over time. The posterior surface of the central region shifted forwards and then backwards, and the surface of the paracentral and peripheral areas shifted forward at different time after surgery. Other types of corneal refractive surgery had similar results. Yan *et al*[25] studied the changes of post-corneal elevation after SBK, and found that the elevation values in the 4- and 6-mm areas of the cornea were significantly higher than the baseline. A similar progressive forward shift was observed in the peripheral corneal region 6mo after epi-LASIK[26]. Despite the changes in ΔPME with anterior and posterior movement, no cases of dilatation after refractive surgery were found in our study.Previous studies had shown that the prostroma (200 μm) near the Bowman layer had higher cohesive tensile strength than the remaining posterior stroma (300 μm). Thus, the prostroma and Bowman's membrane played an important role in maintaining corneal biomechanical stability and tensile strength. Moreover, the peripheral stroma is more malleable, ductile, and tensionic than the central corneal stroma. Zhou *et al*[28] confirmed that the prostroma and peripheral cornea have strong tensile strength and tissue tension. As SMILE is a minimally invasive refractive surgery, most of the anterior stroma layer is retained without touching the anterior elastic layer, so the corneal biomechanical damage is small. Although the tensile strength is decreased, it is still enough to resist the intraocular pressure, so there are no cases of corneal dilation.

At present, there was disagreement about the correlation between postoperative posterior corneal surface height and preoperative parameters of SMILE. The research results of Yu *et al*[21] showed that the change of posterior surface height was positively correlated with SE at the 6-mm ring at 1mo after surgery, positively correlated with AD at the 6-mm ring at 1 and 6mo after surgery, and negatively correlated with RBT at the 2-mm ring at 3mo after surgery, and the rest had no significant correlation. However, Cao *et al*[29] showed that corneal stability after 1y of surgery was negatively correlated with SE, CCT, RBT and PBST, and positively correlated with maximum lenticule thickness and PAD. For each baseline parameter, PME6 showed an opposite correlation trend with other location. Our results showed that the posterior surface of the cornea was significantly shifted forwards in patients with high refractive power, thin cornea, deep cutting, and little residual matrix. Studies have confirmed that the tensile strength of the anterior matrix of the cornea is significantly higher than that of the posterior stroma, so patients with high myopia and thin corneas may lose biomechanical stability due to large cutting volume and insufficient remaining matrix, resulting in posterior corneal elevation. At present, the understanding of the risks of SMILE surgery was still based on the theoretical values of LASIK surgery. In the past, RBT≥250 μm was considered the safe threshold for LASIK surgery. Randleman *et al*[30] proposed 300 μm as a safety threshold. To date, there was no recognized optimal ablation threshold. Therefore, it is still necessary for ophthalmologists to explore the factors that affect the stability of the posterior cornea.

There are some limitations to this study: retrospective study, small sample size, and short follow-up. The results of this study need to be validated in future long-term, prospective studies.

ACKNOWLEDGEMENTS

Foundation: Supported by Shandong Provincial Natural Science Foundation (No.ZR2022QH384).

Conflicts of Interest: Sun XT, None; **Zhang Y,** None; **Mei XK,** None; **Zheng NN,** None; **Niu LZ,** None; **Qu XL,** None; **Song AP,** None; **Zhuo J,** None.

REFERENCES

1 Reinstein DZ, Archer TJ, Randleman JB. Mathematical model to compare the relative tensile strength of the cornea after PRK, LASIK, and small incision lenticule extraction. *J Refract Surg* 2013;29(7):454-460.

2 Moshirfar M, McCaughey MV, Reinstein DZ, Shah R, Santiago-Caban L, Fenzl CR. Small-incision lenticule extraction. *J Cataract Refract Surg* 2015;41(3):652-665.

3 Moshirfar M, Albarracin JC, Desautels JD, Birdsong OC, Linn SH, Sr Hoopes PC. Ectasia following small-incision lenticule extraction (SMILE): a review of the literature. *Clin Ophthalmol* 2017;11:1683-1688.

4 Wang LX, Wang XL, Tang J, Ma K, Yin HB, Deng YP. A 3-month comparison study of subjective and objective visual quality of small incision lenticule extraction and transepithelial photorefractive keratectomy in patients with low and moderate myopia. *Int J Ophthalmol* 2023;16(4):608-615.

5 Lang M, Cao KW, Liu T, Zhu Y, Ye J. Five-year results of refractive outcomes and vision-related quality of life after SMILE for the correction of high myopia. *Int J Ophthalmol* 2021;14(9):1365-1370.

6 Shetty R, Francis M, Shroff R, Pahuja N, Khamar P, Girrish M, Nuijts RMMA, Sinha Roy A. Corneal biomechanical changes and tissue remodeling after SMILE and LASIK. *Invest Ophthalmol Vis Sci* 2017;58(13):5703-5712.

7 Chan TCY, Liu D, Yu M, Jhanji V. Longitudinal evaluation of posterior corneal elevation after laser refractive surgery using swept-source optical coherence tomography. *Ophthalmology* 2015;122(4):687-692.

8 Kymionis GD, Grentzelos MA, Voulgari N. Posterior elevation as a risk factor for corneal ectasia after small-incision lenticule extraction. *J Cataract Refract Surg* 2019;45(10):1523-1524.

9 Gomes JAP, Tan D, Rapuano CJ, Belin MW, Ambrósio R Jr, Guell JL, Malecaze F, Nishida K, Sangwan VS, Group of Panelists for the Global Delphi Panel of Keratoconus and Ectatic Diseases. Global consensus on keratoconus and ectatic diseases. *Cornea* 2015;34(4):359-369.

10 Taneri S, Kießler S, Rost A, Schultz T, Dick HB. Small-incision lenticule extraction for the correction of myopic astigmatism. *J Cataract Refract Surg* 2019;45(1):62-71.

11 Assad M, Chazalon T, Naguszewski D, Muraine M. Small Incision Lenticule Extraction (SMILE) for correction of myopic astigmatism. *J Fr Ophtalmol* 2020;43(9):898-906.

12 Chen P, Ye YM, Yu N, Zhang XY, Zhuang J, Yu KM. Correction of astigmatism with SMILE with axis alignment: 6-month results from 622 eyes. *J Refract Surg* 2019;35(3):138-145.

13 Reinstein DZ, Pradhan KR, Carp GI, Archer TJ, Day AC, Sekundo W, Dhungana P. Small incision lenticule extraction for hyperopia: 3-month refractive and visual outcomes. *J Refract Surg* 2019;35(1):24-30.

14 Gavrilov JC, Atia R, Borderie V, Laroche L, Bouheraoua N. Unilateral corneal ectasia after small-incision lenticule extraction in a 43-year-old patient. *J Cataract Refract Surg* 2018;44(3):403-406.

15 Xie LX, Shi WY, Liu ZG, *et al*. Consensus of Chinese keratoconus diagnosis and treatment experts. *Chin J Exp Ophthalmol* 2019;55(12):891-895.

16 Ruan YM, Zhang Y, Ying XH. Clinical study on the differential diagnosis of high myopia astigmatism and subclinical keratoconus in adolescents by pentacam anterior segment analyzer. *Contrast Media Mol Imaging* 2022;2022:6370791.

17 Oh JH, Kim SH, Chuck RS, Park CY. Evaluation of the Pentacam ray tracing method for the measurement of central corneal power after myopic photorefractive keratectomy. *Cornea* 2014;33(3):261-265.

18 Byun YS, Chung SH, Park YG, Joo CK. Posterior corneal curvature assessment after Epi-LASIK for myopia: comparison of Orbscan II and Pentacam imaging. *Korean J Ophthalmol* 2012;26(1):6-9.

19 Wang TM, Liao RF. Early changes in posterior corneal elevation and related factors after femtosecond laser assisted LASIK and SBK. *Chin J Exp Ophthalmol* 2019;37(2):111-116.

20 Xu XH, Zhang XM, Liu Q. Long-term clinical study on the changes of corneal posterior elevation after SMILE surgery. *Hans J Ophthalmol* 2022;11(2):150-156.

21 Yu CJ, Wang Y, Su XL, Wu WJ, Wu ZQ, Wu YN. An analysis of changes in posterior corneal elevation and relevant factors after small incision lenticule extraction. *Zhonghua Yan Ke Za Zhi* 2016;52(7):494-498.

22 Dong ZX, He L, Sun ZY, Shen Y, Chu RY, Zhou XT. The histopathological observation of rabbit corneas after small incision lenticule extraction. *Zhonghua Yan Ke Za Zhi* 2016;52(7):507-513.

23 Wei SS, Wang Y, Wu D, Zu PP, Zhang H, Su XL. Ultrastructural changes and corneal wound healing after SMILE and PRK procedures. *Curr Eye Res* 2016;41(10):1316-1325.

24 Dawson DG, Edelhauser HF, Grossniklaus HE. Long-term histopathologic findings in human corneal wounds after refractive surgical procedures. *Am J Ophthalmol* 2005;139(1):168-178.

25 Yan PS, Du ZY, Wu NL, Zhang Y, Xu YC. Minor influence of sub-bowman keratomileusis on the posterior corneal surface at early stage. *Curr Eye Res* 2013;38(8):871-879.

26 Zhang L, Wang Y. The shape of posterior corneal surface in normal, post-LASIK, and post-epi-LASIK eyes. *Invest Ophthalmol Vis Sci* 2010;51(7):3468-3475.

27 Zhao Y, Lin X, Chen ZY, Zhou XT. Five-year stability of posterior corneal surface after small incision lenticule extraction for high myopia. *BMC Ophthalmol* 2022;22(1):239.

28 Zhou XY, Shang JM, Qin B, Zhao Y, Zhou XT. Two-year observation of posterior corneal elevations after small incision lenticule extraction (SMILE) for myopia higher than-10 dioptres. *Br J Ophthalmol* 2020;104(1):142-148.

29 Cao HZ, Zhang L, Liang S, Chen X, Jhanji V, Wang Y. Predictive factors of posterior corneal shift after small incision lenticule extraction: a 5-year follow-up study. *Acta Ophthalmol* 2022;100(7):e1431-e1438.

30 Randleman JB, Woodward M, Lynn MJ, Stulting RD. Risk assessment for ectasia after corneal refractive surgery. *Ophthalmology* 2008;115(1):37-50.