SMILE after DALK to reduce residual refraction: two-year results

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Abstract
Purpose To determine the two-year results of small incision lenticule extraction (SMILE) for correcting post-keratoplasty myopia and myopic astigmatism.
Methods In this case-series study, 10 eyes of 10 patients with a 6- to 10-year history of successful deep lamellar keratoplasty (DALK) underwent SMILE using the VisuMax laser platform. Ophthalmologic examinations and visual acuity and refraction measurement were taken pre- and 1, 3, 6, 12, and 24 months postoperatively. The Pentacam and Sirius imaging were done in the first and last follow-up sessions.
Results The mean age of the patients was 39.60 ± 7.86 years. Six subjects were male. Two years after SMILE, the mean improvement in UDVA and CDVA was 3.60 ± 1.84 (P < 0.001) and 1.60 ± 2.91 (P = 0.231) LogMAR, respectively. The mean decrease in spherical equivalent, spherical error, and cylinder power was 1.92 ± 1.96 diopter (D) (P = 0.013), 0.70 ± 3.05D (P = 0.213), and 2.42 ± 2.91D (P = 0.024), respectively. The vector mean target-induced astigmatism, surgical-induced astigmatism, and difference vector were 1.30D@44°, 1.11D@24°, and 0.86D@73°, respectively. Two years after SMILE, vertical coma, horizontal coma, and spherical aberration increased by 0.44 ± 0.51, 0.23 ± 0.32, and 0.02 ± 0.16 µm, respectively, (all P > 0.05) while trefoil reduced by 0.29 ± 0.75 µm (P = 0.428).
Conclusion SMILE can be an effective procedure for reducing refraction and astigmatism after DALK in patients with moderate myopia and moderate to severe astigmatism and improves the visual acuity in these patients. Axis rotation during surgery may result in under-correction of astigmatism. Refinement of SMILE treatment nomogram for post-DALK cases seems necessary.

Keywords Small incision lenticule extraction · Deep lamellar keratoplasty · Myopic astigmatism · Mid-term results

Abbreviations
PK Penetrating keratoplasty
HOA Higher order aberrations
PRK Photorefractive keratectomy
LASIK Laser in situ keratomileusis
SMILE Small incision lenticule extraction
D Diopter
DALK Deep lamellar keratoplasty
CDVA Corrected distance visual acuity
UDVA Uncorrected distance visual acuity
Introduction

Deep anterior lamellar keratoplasty (DALK), a procedure used for corneal stroma replacement with preserving the healthy endothelium, has several advantages compared to penetrating keratoplasty (PK), including better visual outcomes and lower graft failure and rejection rates [1]. Residual refractive error is one of the complications after DALK as well as all other keratoplasty methods for which various methods such as spectacles, contact lenses, and surgical procedures (relaxing incision, excimer laser, and intraocular lenses) have been proposed. Rigid contact lenses have shown better results compared to spectacles; however, they are associated with several drawbacks like intolerance and peripheral neovascularization [2]. Suture-based methods including relaxing incisions, wedge resection, single continuous suture adjustment, and selective suture removal may reduce treatment effectiveness [3].

Refractive surgery methods such as photorefractive keratectomy (PRK) with or without mitomycin C can reduce residual refractive errors after corneal grafting; however, the long-term results of this procedure have shown unacceptable predictability. According to the literature, significant regression, irregular astigmatism induction, limited astigmatic correction, and haziness are among the most important drawbacks of this surgical method [4]. However, according to a recent report, a modified version of this procedure (topography-guided trans-epithelial no-touch PRK) has shown good one-year safety and effectiveness for correcting post-PK high irregular astigmatism with decreased corneal haze and no report of postoperative regression [5]. Laser in situ keratomileusis (LASIK) is preferred to PRK due to better visual and refractive outcomes [6]; however, flap complications and corneal decompensation are the disadvantages of this procedure. Corneal decompensation can be due to graft rejection, graft failure from epithelial and stromal rejection, or loss of endothelial cell count [6, 7]. On the other hand, thinning of the graft-host interface increases the risk of wound dehiscence. Moreover, flap dislocation is increased in eyes with a low endothelial cell count due to possible corneal edema [6]. Toric intraocular lens implantation corrects ameteropia effectively, but this method is also associated with a number of complications including endophthalmitis, endothelial cell loss, and lens rotations [8, 9]. Graft rejection is an important complication of all the above methods.

Small incision lenticule extraction (SMILE) is a new refractive surgery technique for the correction of myopia and myopic astigmatism. Since the epithelium remains intact in this method and a lenticule is extracted from the stroma without flap removal, it is preferred to PRK and LASIK in eyes with no history of ocular surgery. The safety and efficacy of this procedure have been confirmed as well [10, 11]. To the best of our knowledge, only one study investigated the 6-month results of this procedure in post-PK patients [12]. Considering the instability of vision and refraction results after PK, especially in subjects with high astigmatism, the present study was conducted to evaluate the two-year safety, efficacy, predictability, and visual outcomes of SMILE for correcting high post-DALK astigmatism.

Material and methods

This case series was conducted at Noor Eye Hospital, Tehran, Iran, in 2018. The target population was patients that underwent DALK using the big bubble technique due to advanced KC and were scheduled to receive SMILE for correcting astigmatism. The inclusion criteria were age ≥ 20 years, time from corneal grafting ≥ 2 years, time from suture removal > 6 months, a difference of 0.10 LogMAR between corrected distance visual acuity (CDVA) and uncorrected distance visual acuity (UDVA), a residual stromal bed (RSB) of at least 280 µm, consent to participate in the study, and complete follow-up exams. The exclusion criteria were a history of graft rejection, any history of corneal surgery other than keratoplasty, and corticosteroid contraindication. The patients were advised to stop wearing their contact lenses four weeks before surgery.
Ethical considerations

The protocol of the study was approved by the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.MEDICINE.REC.1400.626). The objectives, method, and possibility of incomplete refractive correction in high myopic patients were explained to the subjects, and informed consent was obtained. The study was conducted in accordance with the Declaration of Helsinki.

SMILE procedure

After administering topical anesthesia, the patient was asked to fixate on an internal light source. Standard SMILE was done using the VisuMax laser platform (Carl Zeiss Meditec AG, Jena, Germany). First, the posterior surface of the lenticule was incised from the periphery to the center and then the anterior surface was incised inversely. The lenticule creation parameters were as follows: cap thickness = 120 µm, cap diameter = 7.7 mm, optical zone = 6.5 mm, and transition zone = 0.1 mm for cases with moderate myopia, and cap thickness = 110 µm, cap diameter = 7.2 mm, incision, optical zone = 6.0 mm, transition zone = 0.1 mm for high myopia cases. The postoperative regimen included 0.5% chloramphenicol eye drops (Sina Darou, Tehran, Iran) four times a day for three days, betamethasone 0.1% drops (Sina Darou, Tehran, Iran) four times a day in the first month, two times a day in the second month, and once a day in the third month, and preservative-free artificial tears (Hypromellose) four times a day for one month.

Examinations

The patients were examined before and 1, 3, 6, 12, and 24 months after the SMILE. In addition to slit lamp biomicroscopy (Haag-Streit, Ohio, USA), UDVA and CDVA were measured using the Snellen SC-2000 system (Nidek Inc., Tokyo, Japan). Subjective refraction was measured using retinoscopy (ParaStop HEINE BETA 200; HEINE Optotechnik, Herrsching, Germany) in all visits. Corneal tomography and aberrometry were done using the Pentacam HR (Oculus, Inc., Lynnwood, WA) before and 24 months after SMILE. The refractive maps and Belin/Ambrósio display of the Pentacam were used to evaluate corneal ectasia. Total corneal higher-order aberrations (HOA), total vertical and horizontal coma, total spherical aberrations, and total trefoil were extracted to assess postoperative aberrometric changes.

The patients’ satisfaction was evaluated by a scoring system from 0 to 10 with 0 indicating dissatisfaction and 10 representing maximum satisfaction.

Statistical analysis

Sample size calculation was done using the formula for comparing paired (before–after) differences. Based on an alpha of 0.0083 (0.05/6 for repeated measures), a beta of 0.20, and an effect size and SD of change of 1.14 ± 0.75 D (12), the sample size was calculated at 9, and 10 patients were enrolled in the study.

Statistical analysis was done using the SPSS version 21 (IBM Corp., Armonk, NY, USA) and Microsoft Excel 2010 (Microsoft corp., Redmond, WA, USA). The Alpine method [3] was applied for astigmatic analysis, and the graphs were generated using the AstigMATIC software [14]. The mean values and vectors of surgically induced astigmatism (SIA), target-induced astigmatism (TIA), correction index (CI), difference vector (DV), and index of success (IoS) were calculated to evaluate astigmatic changes. Spherical equivalent refraction (SE) was calculated as spherical error ± ½ cylindrical error. Safety was measured as postoperative CDVA / preoperative CDVA, and efficacy was calculated as postoperative UDVA / preoperative CDVA. Repeated measures analysis of variance (RM ANOVA) was applied to assess refraction stability.

Results

Ten eyes of 10 patients were assessed. The mean age of the participants was 39.60 ± 7.86 years (range: 28.00 to 53.00 years), and six of them were male. The mean time between DALK and SMILE was 9.00 ± 1.41 years (range: 6.00 to 10.00 years). Two years after SMILE, 9 out of 10 patients rated their satisfaction as 10 and one patient rated it as 8.
Vision

Two-year UDVA and CDVA changes are shown in Table 1. Two years after SMILE, the mean uncorrected and corrected distance visual acuity improved from 1.14 ± 0.44 to 0.42 ± 0.29 LogMAR (P < 0.001) and from 0.23 ± 0.18 to 0.13 ± 0.13 LogMAR (P = 0.231), respectively. Two-year safety and efficacy indices were 1.53 ± 1.27 and 0.68 ± 0.33, respectively (Fig. 1).

Refraction

In the second year after SMILE, the mean SE decreased from −4.74 ± 2.63 diopter (D) to −82 ± 2.33 diopter (D).

Table 1 Mean ± standard deviation (SD) of visual and refractive parameters in post-keratoplasty eyes treated with small incision lenticule extraction (n = 10)

|                  | UDVA (logMAR) | CDVA (logMAR) | SE (D)   | Sphere (D) | Cylinder (D) |
|------------------|---------------|---------------|----------|------------|--------------|
| Baseline         | 1.14 ± 0.44   | 0.23 ± 0.18   | −4.74 ± 2.63 | −1.92 ± 3.04 | −5.62 ± 2.95 |
| At 1 month       | 0.58 ± 0.46   | 0.25 ± 0.24   | −1.76 ± 2.05 | −0.32 ± 2.18 | −2.87 ± 1.68 |
| At 3 months      | 0.59 ± 0.47   | 0.16 ± 0.17   | −1.75 ± 1.88 | −0.15 ± 2.34 | −3.20 ± 1.86 |
| At 6 months      | 0.59 ± 0.42   | 0.17 ± 0.16   | −2.05 ± 2.15 | −0.52 ± 2.53 | −3.05 ± 2.03 |
| At 1 year        | 0.54 ± 0.44   | 0.12 ± 0.13   | −2.17 ± 2.09 | −0.67 ± 2.62 | −3.10 ± 2.19 |
| At 2 years       | 0.42 ± 0.29   | 0.13 ± 0.13   | −2.82 ± 2.33 | −1.22 ± 2.64 | −3.20 ± 1.84 |
| P-value*         | < 0.001       | 0.231         | 0.013     | 0.135      | 0.024        |

P-values show the significant changes

*Based on repeated measures analysis of variance

UDVA: uncorrected distance visual acuity; CDVA: corrected distance visual acuity; SE: spherical equivalent

![Fig. 1 Two-year visual results after small incision lenticule extraction in post-keratoplasty patients. Uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA)](https://example.com)
D \ (P=0.013) and two eyes were emmetropic (Table 1). According to Table 2, the mean SD was $-1.76 \pm 2.05$ D in the first month postoperatively ($P=0.022$) and the significant difference with baseline was maintained until the end of the second year postoperatively (all $P<0.05$). However, no significant difference was observed between other follow-ups and the results were stable (all $P>0.05$). A difference of $1.06 \pm 1.00$ D was observed in the second year compared to the first year, which was not statistically significant ($P=0.128$). This one-diopter regression was due to the fact that although SE reduced between 0.25 and 5.88 D in nine eyes, it increased by 1.0 D in one patient. In this case, UDVA did not change while CDVA improved by 8 lines (Fig. 1). The mean spherical error reduced from $-1.92 \pm 3.04$ D to $-0.67 \pm 2.62$ D ($P=0.135$) (Table 1 and Fig. 2). The mean cylindrical error reduced from $-5.62 \pm 2.95$ D to $-3.20 \pm 1.84$ D two years postoperatively ($P=0.024$) (Table 1).

Table 2 Mean target-induced astigmatism (TIA), surgically induced astigmatism (SIA), correction index (CI), difference vector (DV), and index of success (IoS) two years after small incision lenticule extraction (SMILE) in cases with a history of keratoplasty.

|        | TIA  | SIA  | CI   | DV   | IoS |
|--------|------|------|------|------|-----|
| Case 1 | 1.50 | 0.25 | 0.17 | 1.25 | 0.83 |
| Case 2 | 7.00 | 3.64 | 0.52 | 3.36 | 0.48 |
| Case 3 | 4.00 | 1.54 | 0.38 | 2.46 | 0.62 |
| Case 4 | 4.50 | 0.75 | 0.17 | 3.75 | 0.83 |
| Case 5 | 4.25 | 3.00 | 0.71 | 1.25 | 0.29 |
| Case 6 | 12.00 | 10.00 | 0.83 | 2.00 | 0.17 |
| Case 7 | 6.00 | 1.00 | 0.17 | 5.00 | 0.83 |
| Case 8 | 8.00 | 2.25 | 0.28 | 5.75 | 0.72 |
| Case 9 | 6.00 | 2.22 | 0.37 | 3.78 | 0.63 |
| Case 10 | 3.00 | 2.26 | 0.75 | 0.74 | 0.25 |

The two-year mean values of SIA, TIA, CI, DV, and IoS were $2.69 \pm 2.77$ D, $5.62 \pm 2.95$ D, $0.43 \pm 0.25$ D, $2.93 \pm 1.68$ D, and $0.56 \pm 0.25$ D, respectively. Table 2 presents the mean values of these indices for each subject. The vector mean TIA, SIA, and DV were $1.30$ D@$44^\circ$, $1.11$ D@$24^\circ$, and $0.86$ D@$73^\circ$, respectively. The polar graph of these indices is shown in Fig. 3.

### Aberrations

The mean HOAs, vertical coma, horizontal coma, and spherical aberration increased from $3.44 \pm 0.72$
to 3.73 ± 0.82 µm, from 1.84 ± 0.78 to 2.27 ± 1.03 µm, from 1.47 ± 0.87 to 1.70 ± 0.97 µm, and from 1.59 ± 0.37 to 1.61 ± 0.38 µm, respectively, but none of the changes were significant (all P > 0.05). The mean trefoil reduced from 1.27 ± 0.81 to 0.97 ± 0.21 µm (P = 0.428) (Table 3).

Complications

All procedures were completed uneventfully, and there was no case of suction loss during the operation. In one case (patient number 7), CDVA reduced from 0.20 to 0.40 LogMAR but UDVA improved from 1.00 to 0.70 LogMAR. This patient had a CDVA of 0.20 LogMAR at baseline and 0.70

| Table 3 Mean ± standard deviation (SD) of higher-order aberrations (HOAs) in post-keratoplasty eyes treated with small incision lenticule extraction (n = 10) |
|---------------------------------------------------------------|
| HOA (µm) | Vertical coma (µm) | Horizontal coma (µm) | Spherical aberration (µm) | Trefoil (µm) |
| Baseline  | 3.44 ± 0.72 | 1.84 ± 0.78 | 1.47 ± 0.87 | 1.59 ± 0.37 | 1.27 ± 0.81 |
| At 1 month | 3.66 ± 0.81 | 2.01 ± 0.79 | 1.62 ± 0.77 | 1.62 ± 0.41 | 0.99 ± 0.79 |
| At 3 months | 3.67 ± 0.86 | 1.99 ± 0.77 | 1.65 ± 0.79 | 1.61 ± 0.39 | 0.99 ± 0.63 |
| At 6 months | 3.69 ± 0.76 | 2.18 ± 0.68 | 1.71 ± 0.86 | 1.61 ± 0.38 | 1.00 ± 0.56 |
| At 1 year | 3.72 ± 0.79 | 2.23 ± 0.93 | 1.68 ± 0.90 | 1.63 ± 0.42 | 0.98 ± 0.34 |
| At 2 years | 3.73 ± 0.82 | 2.27 ± 1.03 | 1.70 ± 0.97 | 1.61 ± 0.38 | 0.97 ± 0.21 |
| P-value* | 0.302 | 0.129 | 0.185 | 0.744 | 0.428 |

*Based on repeated measures analysis of variance
LogMAR in the one-month follow-up; however, it improved to 0.60 LogMAR in the third month and 0.50 LogMAR in the twelfth month, reaching 0.40 LogMAR in the second year. Spherical error remained unchanged, and astigmatism reduced by 1.0 D in the same axis.

Patient number 5 developed stromal rejection one week after SMILE, and UDVA and CDVA decreased to 1.30 LogMAR and 0.50 LogMAR, respectively. After oral administration and subtenon injection of corticosteroids, the above parameters improved to 0.50 and 0.10 LogMAR, respectively, and the graft cleared completely. UDVA and CDVA improved to 0.30 and 0.00 LogMAR in the second year, respectively, and there was no need for repeat transplantation. The details of this case are presented in another paper [15].

No other complications were observed in the rest of the patients during the two-year follow-up.

Discussion

Residual refractive error is one of the complications in patients with a history of successful PK and lamellar procedures. The proposed surgical and non-surgical methods to manage this undesirable outcome either lack acceptable effectiveness or are associated with further complications, and there is no standard method for the treatment of post-keratoplasty refractive error [12]. SMILE is suggested as a safe, efficacious, predictable, and stable method for correcting myopic and astigmatic error in non-operated eyes [16–18] and is thus a promising method for treating high residual refractive errors after keratoplasty. To the best of our knowledge, this is the first case series with a mid-term follow-up investigating the efficacy and safety of SMILE for correcting post-DALK refractive error in patients with moderate myopia (mean: 4.7 D) and high astigmatism (mean: 5.6 D). Massoud et al. [12] reported that the short-term (6 month) results of this procedure were acceptable in post-PK patients who had high myopia (mean: 6.8 D) and moderate astigmatism (mean: 3.1 D).

Vision

The two-year results suggest that SMILE is a safe procedure for post-DALK refractive correction. The mean CDVA improved from 0.23 LogMAR to 0.13 LogMAR indicating an acceptable safety index (1.53). In a study by Massoud et al. [12], CDVA reduced from 0.73 LogMAR to 0.82 LogMAR six months after the procedure and the safety index was 1.12, but none of the cases experienced reduced CDVA. However, in the present study, CDVA reduced in one of the patients in the first month, which improved gradually from the third month to the 24th month. Considering the trend of improvement after the third month, patients are expected to regain their original or a better visual acuity in the next follow-ups. A study that analyzed the results of post-PK refractive surgery procedures found a 0.1 LogMAR loss of CDVA after PRK (from 0.45 to 0.36) and a 0.04 LogMAR loss of CDVA after LASIK (from 0.39 to 0.35) (19). Since the prevalence of CDVA loss ≥ 1 line is 1.04% after SMILE and 0.51% after LASIK [20] in normal subjects with no history of PK, it seems that our results are acceptable compared to other corrective methods applied to post-PK eyes.

The results showed an efficacy of about 0.7. As demonstrated in Fig. 1, postoperative UDVA was one line better than the preoperative CDVA in one of the cases (patient number 3), and postoperative UDVA reached preoperative CDVA despite stromal rejection in another case (patient number 5). In three eyes, postoperative UDVA was one line worse than preoperative CDVA. In the remaining five cases, differences of 2 to 4 lines were observed. In these cases, although the postoperative UDVA did not reach the preoperative CDVA, it improved by 1–4 lines. Massoud et al. [12] reported a 6-month efficacy of 0.93. The difference might be due to the shorter follow-up time although, given the subjective nature of the test, the precision of the examiner and patient status might influence the results as well. For femtosecond laser-assisted arcuate keratotomy, Fadlallah et al. [21] reported one- and two-year efficacy rates of 0.81 and 0.67, respectively. An efficacy of 1.04 has been reported in normal subjects with moderate to high myopic astigmatism. It seems that the efficacy of this procedure is lower in post-keratoplasty cases compared to normal subjects.

Refration

SE decreased postoperatively in all eyes and the results were stable until the end of the second year.
In one case (patient number 6), despite a decrease in SE postoperatively compared to baseline, a one-diopter increase was observed after the first month. In this case, due to inconsistency between UDVA (no change) and CDVA (8 lines improvement), it can be stated that the increase in SE resulted from poor repeatability of SE measurement in the keratoplastic corneas.

SE and spherical error decreased by about 2.0 and 1.2 D, respectively. Massoud et al. [12] reported a mean reduction of 4.5 and 5.4 D in SE and spherical error after six months, respectively. There were no cases of over-correction in our study; however, the over-corrected cases in the above study may experience different results in the long term. Kovoor et al. [19] found a spherical error reduction of 3.6 D after PRK. This decrease was 1.94D in a study by Shen et al. [22].

One reason for the lower spherical correction in our study could be the lower preoperative sphere. The mean preoperative sphere was 1.9 D in our study, 5.3 D in the study by Massoud et al. [12], 5.1 D in the study by Kovoor et al. [19], and 2.6 D in the study by Shen et al. [22].

Two years after SMILE, astigmatism reduced by 0.75 to 10.0 D in eight cases and remained unchanged in two cases (0.25 D). According to the results of vector analysis, SIA, TIA, and DV were 2.7 D, 5.6 D, and 2.9 D in our study, respectively. These values were 2.1 D, 2.6 D, and 1.1 D in the study by Massoud et al. [12]. IoS was 0.6 in the present study, indicating that SMILE corrected up to 60.0% of post-DALK astigmatism. Regardless of the differences in the surgical technique (PK and DALK) and follow-up time between the two studies, the mean error of astigmatic correction increases in the presence of high astigmatism, and this direct correlation is confirmed in normal subjects [23]. Studies have shown that in normal corneas, the probability of residual astigmatism increases by up to 16% for each one-diopter increase in astigmatism [16]. The difference in axis orientation of TIA, SIA, and DV indices suggests that astigmatism axis rotation is one of the reasons for under-correction. Another reason of under-correction is irregular astigmatism before SMILE. A previous study found a correlation between poor visual outcomes and irregular astigmatism in these cases [24]. In addition, according to the available nomograms, astigmatic correction in patients with no history of keratoplasty requires 10% adjustment [21, 23]. As such, patients with a history of keratoplasty might need further readjustment. In addition, lack of automated cyclotorsion control and centration in Visumax could be another reason for under-correction with SMILE compared to other methods [25]. Furthermore, irregular astigmatism can be associated with under-correction.

**Aberrations**

HOAs except trefoil showed a nonsignificant increase in the present study. HOA changes had a similar trend to normal corneas undergoing SMILE [11]. Two points should be kept in mind. The first one is the contribution of these changes to the quality of vision and visual function, since visual performance is affected by adaptation, scatter, and neural adaptation [26]. The patients’ satisfaction with the outcomes indicated that the increase in aberrations did not impair their quality of vision, or the reduced quality was negligible compared to the gain in visual acuity. The second point is the repeatability of aberration measurements in grafted corneas. To the best of our knowledge, no study has evaluated the repeatability of these indices (measured by the Sirius) in subjects undergoing DALK. A study reported a within-subject standard deviation of 0.01 to 0.05 µm in these indices in patients with keratoconus [27]. However, post-keratoplasty corneal irregularities reduce the repeatability of the measurements. If these data were available for grafted corneas, comparison of the 2 year changes of these indices with their measurement error could improve our conclusion.

**Complications**

As mentioned earlier, only one eye (10%) experienced stromal rejection in the present study, which occurred one week after SMILE. The reported rate of graft rejection after successful DALK is 7.1% [28], which can occur by up to 46 months after grafting [29]. In our case, the patient had no complications for 9 years after DALK, but the graft rejected within a week after an uneventful and successful SMILE. Interestingly, 3.75 D astigmatic correction and 4 lines of UDVA improvement were observed on the first postoperative day. Graft
rejection could be attributed to the release of inflammatory mediators, as high dose topical and systemic betamethasone reversed the process. In this regard, it might be helpful to prescribe a higher dose and longer course of corticosteroids and monitor the patients closely for potential graft rejection.

In conclusion, according to the 2-year results, SMILE may be a safe, effective, predictable, and stable method for reducing post-DALK refractive error. A limitation of the study was the lack of clinical trial registry. SMILE is an uncommon procedure in these cases and it would be better if the study protocol had been registered in a database. Although the present study had a small sample size and a single-arm design without a control group, the results provide valuable information regarding the application of this procedure for correction of post-DALK residual refractive error. Under-correction of astigmatism may be due to axis rotation during surgery and irregular astigmatism before SMILE. Refinement of the SMILE treatment nomogram for post-DALK cases seems necessary. This procedure can facilitate the use of spectacles or even contact lenses through improving vision and reducing refraction. However, considering the possibility of graft rejection, longer durations of corticosteroid therapy and more intensive monitoring are required in the postoperative period.

Authors’ contributions: Design of study (HH and SA); Data collection (MM); Analysis and interpretation of data (SA, SS, and AM); Writing of article (SA and MM); Critical revision and final approval of article (All authors).

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Availability of data and materials The data are presented in the text.

Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethical approval Approval for this study was obtained from the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.MEDICINE.REC.1400.626). The study adhered to the tenets of the Helsinki Declaration at all stages. Prior to enrollment, the goals and methods of the study were explained to the patients and signed informed consents were obtained.

Consent for publication Not applicable.

References

1. Yu AC, Spena R, Pellegrini M, Bovone C, Busin M (2021) Deep Anterior Lamellar Keratoplasty: Current Status and Future Directions. Cornea. https://doi.org/10.1097/ICO.0000000000002840
2. Imamoglu S, Kaya V, Oral D, Perente I, Basarir B, Yilmaz OF (2014) Corneal wavefront-guided customized laser in situ keratomileusis after penetrating keratoplasty. J Cataract Refract Surg 40:785–792
3. Krachmer JH, Fenzl RE (1980) Surgical correction of high postkeratoplasty astigmatism. Relaxing incisions vs wedge resection. Arch Ophthalmol. 98:1400–1402
4. Bilgihan K, Ozdek SC, Akata F, Hasanreisoglu B (2000) Photorefractive keratectomy for post-penetrating keratoplasty myopia and astigmatism. J Cataract Refract Surg 26:1590–1595
5. Spadea L, Visioli G, Mastromarino D, Alexander S, Pistella S (2021) Topography-Guided Trans-Epithelial No-Touch Photorefractive Keratectomy for High Irregular Astigmatism After Penetrating Keratoplasty: A Prospective 12-Months Follow-Up. Ther Clin Risk Manag 17:1027–1035. https://doi.org/10.2147/TCRM.S329932
6. Kurjan J, Channa P (2010) Refractive surgery after corneal transplant. Curr Opin Ophthalmol 21:259–264
7. Hardten DR, Chittcharus A, Lindstrom RL (2002) Long-term analysis of LASIK for the correction of refractive errors after penetrating keratoplasty. Trans Am Ophthalmol Soc. 100:143–50
8. Srinivasan S, Ting DS, Lyall DA (2013) Implantation of a customized toric intraocular lens for correction of post-keratoplasty astigmatism. Eye 27:531–537
9. Tahzib NG, Cheng YY, Nuijts RM (2006) Three-year follow-up analysis of Artisan toric lens implantation for correction of postkeratoplasty ametropia in phakic and pseudophakic eyes. Ophthalmology 113:976–984
10. Sia RK, Ryan DS, Beydoun H, Eaddy JB, Logan LA, Rodgers SB et al (2020) Visual outcomes after SMILE from the first-year experience at a U.S. military refractive surgery center and comparison with PRK and LASIK outcomes. J Cataract Refract Surg 46:995–1002
11. Miraftab M, Hashemi H, Aghamirsalim M, Fayyaz S, Asgari S (2021) Matched comparison of corneal higher order aberrations induced by SMILE to femtosecond assisted LASIK and to PRK in correcting moderate and high myopia: 3.00mm vs. 6.00mm. BMC Ophthalmol. 21:216
12. Massoud TH, Ibrahim O, Shehata K, Abdalla MF (2016) Small incision lenticule extraction for postkeratoplasty myopia and astigmatism. J Ophthalmol 2016:3686380
13. Alpins N (2001) Astigmatism analysis by the Alpins method. J Cataract Refract Surg 27:31–49
14. Gauvin M, Wallerstein A (2018) AstigmatMATIC: an automatic tool for standard astigmatism vector analysis. BMC ophthalmol 18:255
15. Hashemi H, Aghamirsalim M, Asgari S (2019) Stromal Rejection After SMILE for the Correction of Astigmatism After Graft. J Refract Surg 35:737–739
16. Ivarsen A, Hjortdal J (2014) Correction of myopic astigmatism with small incision lenticule extraction. J Refract Surg 30:240–247

17. Khalifa MA, Ghoneim AM, Shaheen MS, Piñero DP (2017) Vector analysis of astigmatic changes after small-incision lenticule extraction and wavefront-guided laser in situ keratomileusis. J Cataract Refract Surg 43:819–824

18. Zhang J, Wang Y, Chen X (2016) Comparison of Moderate- to High-Astigmatism Corrections Using WaveFront-Guided Laser In Situ Keratomileusis and Small-Incision Lenticule Extraction. Cornea 35:523–530

19. Kovoor TA, Mohamed E, Cavanagh HD, Bowman RW (2009) Outcomes of LASIK and PRK in previous penetrating corneal transplant recipients. Eye Contact Lens 35:242–245

20. Zhang Y, Shen Q, Jia Y, Zhou D, Zhou J (2016) Clinical outcomes of SMILE and FS-LASIK used to treat myopia: a meta-analysis. J Refract Surg 32:256–265

21. Fadlallah A, Mehanna C, Saragoussi JJ, Chelala E, Amari B, Legeais JM (2015) Safety and efficacy of femtosecond laser-assisted arcuate keratotomy to treat irregular astigmatism after penetrating keratoplasty. J Cataract Refract Surg 41:1168–1175

22. Shen E, Tsai L, Muniz Castro H, Wade M, Farid M (2019) Femtosecond laser-assisted in situ Keratomileusis treatment of residual refractive error following femtosecond laser-enabled Keratoplasty. J Ophthalmol 2019:8520183

23. Zhang J, Wang Y, Wu W, Xu L, Li X, Dou R (2015) Vector analysis of low to moderate astigmatism with small incision lenticule extraction (SMILE): results of a 1-year follow-up. BMC Ophthalmol 15:8

24. Tomida D, Yamaguchi T, Ogawa A, Hirayama Y, Shimazaki-Den S, Satake Y, Shimazaki J (2015) Effects of corneal irregular astigmatism on visual acuity after conventional and femtosecond laser-assisted Descemet’s stripping automated endothelial keratoplasty. Jpn J Ophthalmol 59(4):216–222. https://doi.org/10.1007/s10384-015-0388-y

25. Swami AU, Steinert RF, Osborne WE, White AA (2002) Rotational malposition during laser in situ keratomileusis. Am J Ophthalmol 133:561–562

26. Pantanelli SM, Sabesan R, Ching SS, Yoon G, Hindman HB (2012) Visual performance with wave aberration correction after penetrating, deep anterior lamellar, or endothelial keratoplasty. Invest Ophthalmol Vis Sci 53:4797–4804

27. Bayhan HA, Aslan Bayhan S, Muhafiz E, Can I (2014) Repeatability of aberrometric measurements in normal and keratoconus eyes using a new Scheimpflug-Placido topographer. J Cataract Refract Surg 40:269–275

28. Liu H, Chen Y, Wang P, Li B, Wang W, Su Y, Sheng M (2015) Efficacy and safety of deep anterior lamellar keratoplasty vs penetrating keratoplasty for myopia: a meta-analysis. PLoS One 10:e0113332

29. Roberts HW, Maycock NJ, O’Brart DP (2016) Late stromal rejection in deep anterior lamellar keratoplasty: a case series. Cornea 35:1179–1181

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