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ORIGINAL ARTICLE

Correction of myopic astigmatism by small incision lenticule extraction: does laterality matter?

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Abstract

To evaluate the outcome after astigmatic correction of small incision lenticule extraction (SMILE) and to compare the refractive results of right eyes with left eyes. Patients who underwent SMILE surgery in our clinic between 2014 and 2016 (Visumax, Carl Zeiss Meditec, Germany) were retrospectively reviewed. Preoperative and postoperative manifest refractions and corrected and uncorrected visual acuities were evaluated and changes in refractive astigmatism were evaluated by vector analysis. One hundred twenty-one eyes from 82 patients with myopic astigmatism were included. The mean preoperative spherical equivalent was − 6 ± 1.7 (range from − 9.50 to − 1.25) D and the mean cylinderical power was − 1.5 ± 0.6 (range from − 3.75 to − 1.00) D. Postoperatively 71.8% of eyes had < 0.50 D cylinder magnitude. Vector analysis results based on laterality revealed that correction index was 0.87 ± 0.3 for left eyes and 0.72 ± 0.3 for right eyes (p 0.02). This study revealed that SMILE has favorable astigmatic correction affect but left eyes have better outcomes than right eyes.

Keywords SMILE · Vector analysis · Astigmatism · Laterality

Introduction

Small incision refractive lenticule extraction (SMILE) is a recent advancement in refractive surgery based on the extraction of a refractive lenticule through a peripheral incision created by femtosecond laser [1]. Currently, the procedure allows the correction of myopia and myopic astigmatism with comparable results to femtosecond assisted laser [2]. This technique gained widespread acceptance because it is flapless and preserves more corneal nerves [3, 4]. On the other side, the major disadvantage is the lack of iris registration with eye-tracking system and decompensation of cyclotorsion. These factors may lead to lower predictability for astigmatic correction [5]. Treatment parameters may vary among studies utilizing SMILE [6]. Energy settings [7], localization of peripheral incision where the lenticule is extracted through [1, 3, 8, 9], and the size of the opening [10, 11] are all variables among studies. But there is too limited knowledge about the effect of laterality on astigmatic correction [9].

In this study, we aimed to evaluate the outcome of SMILE in patients with astigmatism ≥ 1.0 D by vector analysis in long-term follow-up and compare the results for right eyes with the left.

Materıal methods

This study was designed in retrospective manner with consecutive patients who received SMILE between January 2014 and December 2016 at the Beyoglu Eye Training and Research Hospital, Refractive Surgery Department in Istanbul. An informed consent was obtained from all participants. The study adhered to the tenets of the Declaration of Helsinki. İnclusion criteria were (1) unsatisfactory correction with spectacles or contact lenses, (2) age over 20, (3) myopic patients with ≥ 1.0 Diopter (D) astigmatism, (4) stable refraction for more than 1 year, and (5) manifest spherical equivalent of − 1 to − 9 D. All eyes had emmetropia as the target refraction. Only patients who had undergone SMILE for both eyes in the same operation session were included.

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Patients with corneal thickness of < 500 μm, suspicion of keratoconus on corneal topography (displacement of the corneal apex, decrease in thinnest-point pachymetry, asymmetric topographic pattern), ocular infection, dry eye syndrome, and postoperative follow-up time less than 3 months were exclusion criteria for SMILE.

Preoperative examination data included uncorrected and best corrected visual acuity (logMAR), spherical equivalent, dilated fundoscopy examinations, manifest refraction, and cycloplegic refraction measurements (KR-1 Auto Kerato-Refractometer, Topcon, Japan). The Sirius corneal topography and aberrometry system (6 mm pupil diameter, Costruzioni Strumenti Oftalmici, Italy) was used for corneal topography, dynamic infrared pupillography, ocular wavefront analysis, and corneal wavefront analysis.

Surgical technique

All procedures within the scope of this study were performed by the same surgeon using the VisuMax (Carl Zeiss Meditec, Germany) femtosecond laser platform using the same laser settings. Spot size was 3 μm for lamellar incisions and 2 μm for sidecuts. Other settings were as follows: spot energy was 140 nJ, minimum lenticule edge thickness was 15 μm, lenticule sidecut angle was 120°, and optical zone was 6.5 mm. The cap was planned to have a diameter of 7.5 mm with a 50° side cut. The parameters for both eyes were identical apart from the location of the peripheral incision. The peripheral incision was set on the temporal side for the right eye while a superior incision was set for the left. A small interface was used for all patients. After making the lenticule cut and sidecut and moving the patient under the surgical microscope, a blunt spatula was used to enter the area of anterior lamellar photodisruption and remove any residual material. The same procedure was performed on the posterior lamellar photodisruption surface. After ensuring the complete separation of the lenticule from the overlying and underlying stroma, the lenticule was removed through the sidecut using forceps.

Assessment of visual and refractive outcomes

Postoperative best corrected visual acuities, manifest refraction measurements, and spherical equivalent values were recorded at the last visit. Vector analysis was done by vector analysis program of Sait Egrilmez [12] based on Alpin's method [13]. Basically, the surgically induced astigmatism (SIA), target-induced astigmatism (TIA), astigmatic correction index, angle of error, magnitude of error, difference vector, index of success, and flattening index were analyzed. The SIA is the vector magnitude of the actual change induced by surgery. The TIA is the vector magnitude of the intended change after surgery. The astigmatic correction index is the ratio of SIA to TIA. The angle of error is the difference between the angles of the SIA and TIA. The difference vector is the magnitude of astigmatic correction from the achieved result that is required to obtain the targeted goal. The index of success is calculated by dividing the difference vector by the TIA. An astigmatic correction index of 1.00 and an index of success of 0 indicate that the desired results have been obtained. The flattening effect is the amount of astigmatism reduction achieved by the effective proportion of the SIA at the intended meridian (flattening effect = SIA cos2Å~angle of error). The flattening index, which preferably equals 1, is obtained by dividing the flattening effect by the TIA. These vector analysis results were compared between right and left eyes.

Statistical analysis

All statistical analyses were performed using SPSS version 20 (SPSS Inc., Chicago, IL, USA). Wilcoxon signed-rank and Chi-square tests were used to compare continuous and categorical variables, respectively. A p value less than 0.05 was defined as statistically significant.

Results

This study evaluated 121 eyes of 82 patients with a mean age of 27.8 ± 5.7 (19–44). There were 50 (61%) female and 32 (39%) male patients. Mean follow-up time was 15 ± 7 months (3–23). Seventy-five (61%) right and 46 (37%) left eyes were evaluated. The mean preoperative spherical equivalent was − 6 ± 1.7 (range from − 9.50 to − 1.25) D and the mean cylinderical power was − 1.5 ± 0.6 (range from − 3.75 to − 1.00) D. The mean manifest spherical equivalent and manifest

Table 1 Preoperative and postoperative characteristics of patients undergoing SMILE

	Preoperative	Postoperative	*p* value
UCVA (LogMAR)	1.4 ± 0.36	0.05 ± 0.01	< 0.001
BCVA (LogMAR)	0.07 ± 0.1	0.04 ± 0.07	< 0.001
Spherical equivalent (D) (min–max)	− 6 ± 1.7 (− 9.50–(−)1.25)	− 0.44 ± 0.5 (− 2–0.75)	0.002
Cylinder (D)	− 1.5 ± 0.6 (− 3.75–(−)1.00)	− 0.43 ± 0.4 (− 2–0)	< 0.001
Right	− 1.39 ± 0.65	− 0.5 ± 0.4	0.922
Left	− 1.4 ± 0.6	− 0.3 ± 0.2	0.019

Table 2 Vector Analysis of astigmatic correction after SMILE using Alpins method

	Total	Right	Left	*p* value[a]
SIA (D) (min–max)	0.97 ± 0.6 (0.20–2.91)	0.9 ± 0.5 (0.14–2.86)	1.17 ± 0.5 (0.22–2.91)	0.049
TIA (D) (min–max)	1.27 ± 0.6 (0.78–3.31)	1.3 ± 0.5 (0.78–3.31)	1.3 ± 0.5 (0.78–2.87)	0.62
DV (min–max)	0.62 ± 0.4 (0–2.1)	0.67 ± 0.4 (0–2.14)	0.53 ± 0.3 (0.02–2.86)	0.107
ME (min–max)	− 0.28 ± 0.4 (− 1.27–1.38)	− 0.35 ± 0.4 (− 1.27–1.38)	− 0.18 ± 0.3 (− 0.94–0.52)	0.033
AE (min–max)	0 ± 21 (− 77–87)	2.3 ± 24 (− 63–87)	− 5.5 ± 15 (− 77–16)	0.053
CI (min–max)	0.78 ± 0.3 (0.24–1.86)	0.59 ± 0.4 (0.16–2.13)	0.75 ± 0.4 (0.24–1.56)	0.055
CA (min–max)	0.98 ± 0.08 (− 1. 13–2.86)	0.8 ± 0.7 (− 0.67–2.86)	1 ± 0.6 (− 1. 13-2.85)	0.051
FI (min–max)	0.66 ± 0.04 (− 1. 13–2.86)	0.72 ± 0.3 (− 0.72–2.05)	0.87 ± 0.3 (− 1.33–1.36)	0.055
IS (min–max)	0.87 ± 0.1 (0–6.86)	1.13 ± 1.2 (0–6.86)	0.65 ± 0.7 (0.01–3.71)	0.023

[a] Comparison between right and left

AE, angle of error; *CA*, coefficient of adjustment, *CI*, correction index; *DV*, difference vector; *FI*, flattening index; *IS*, index of success; *ME*, magnitude of error; *SIA*, surgically induced astigmatism; *TIA*, target-induced astigmatism

cylinder regressed substantially postoperatively (Table 1). Postoperatively, 71.8% of eyes had < 0.50 D cylinder magnitude. Postoperative cylinder values were lower for left eyes although preoperative measurements were similar (Table 1). Vector analysis results at the last visit were shown in Table 2 and Fig. 1. Scotter plot analysis of SIA versus TIA at the end of follow-up time is shown on Fig. 2. The correction index (CI) defined as the ratio of SIA to TIA was 0.78 ± 0.3 (0.24–1.86). Index of success (IS) defined as difference vector divided by TIA was 0.87 ± 0.1. Angle of error and magnitude of error were 0.62 ± 0.46 (0–2.14) and − 0.28 ± 0.4 (− 1.27–1.38) (Fig. 3). The efficacy index, which was calculated as the ratio of postoperative UDVA over preoperative CDVA, 0.88 ± 0.16 (Fig. 4). The safety index, which was determined as the ratio of postoperative CDVA over preoperative CDVA was 0.96 ± 0.05.

Vector analysis results based on laterality revealed that correction index was 0.87 ± 0.3 for left eyes and 0.72 ± 0.3 for right eyes (*p* 0.02). Index of success which is preferred to be close to "0" is 1.13 ± 1.2 for right eyes and 0.65 ± 0.7 for left eyes (*p* 0.02). Magnitude of error was − 0.35 ± 0.4 for right eyes and − 0.18 ± 0.3 for left eyes (*p* 0.03). Other parameters of vector analysis for right and left eyes are shown on Table 2.

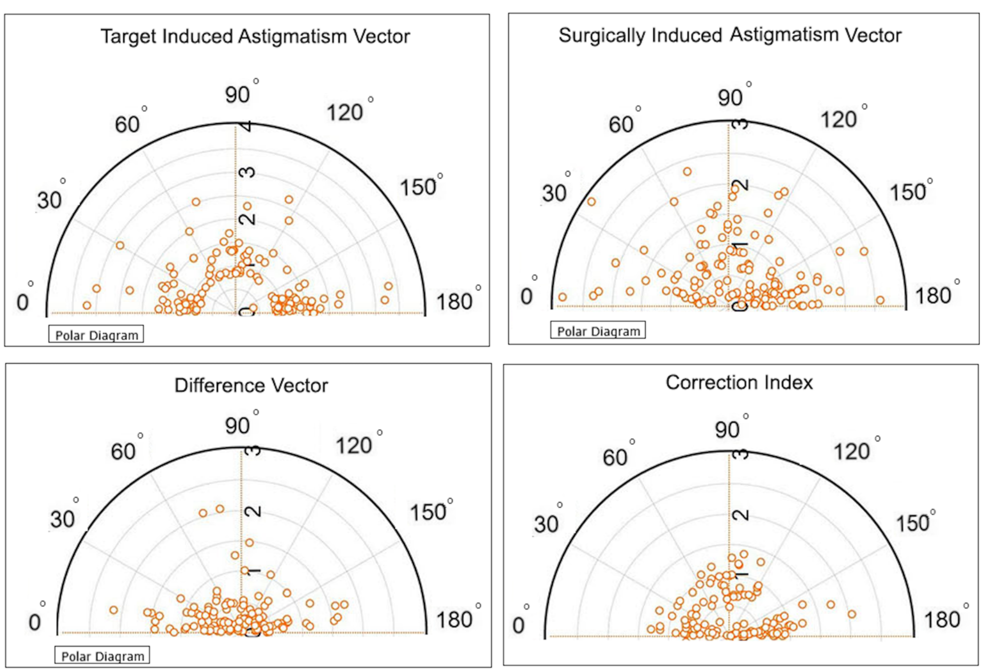
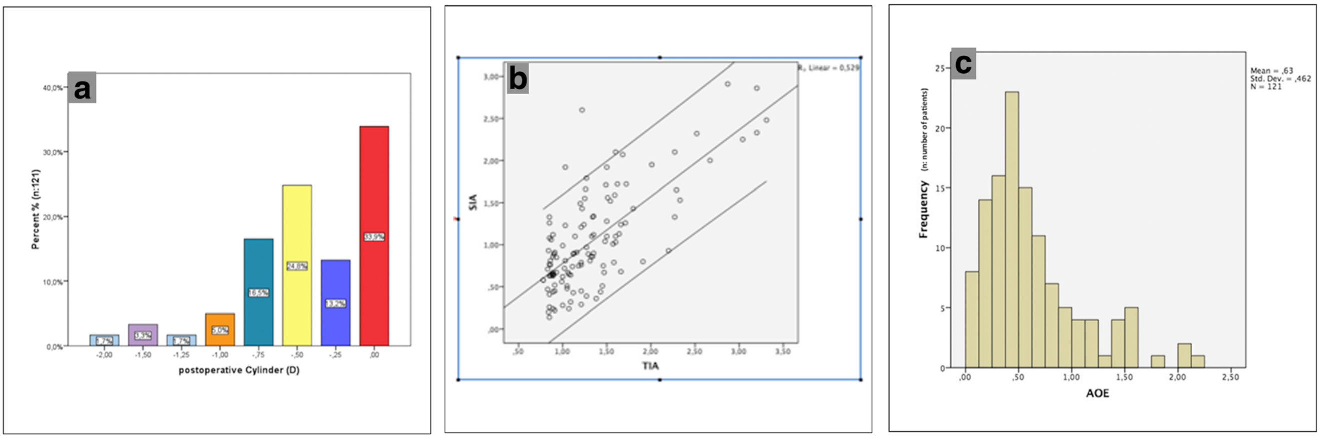


Fig. 1 Single angle polar plots for astigmatism correction based on the Alpins method



Refractive Astigmatism

Target Induced Astigmatism vs Surgically Induced Astigmatism

Refractive Astigmatism Angle of Error

Fig. 2 **a** Postoperative refractive astigmatism. **b** Target-induced astigmatism vs surgically induced astigmatism. **c** Postoperative refractive astigmatism values for angle of error

Discussion

Previous studies have attempted to evaluate the efficacy, safety, and predictability of SMILE [1, 3, 14]. Recently, Ivarsen et al. studied on 775 eyes of 403 patients treated with SMILE and reported that SMILE in myopic astigmatism offers predictable correction of spherical equivalent but a small significant undercorrection of the astigmatic error. The astigmatic undercorrection measured 13% per diopter of attempted correction for low (< 2.50 D) and 16% per diopter for high (> 2.50 D) astigmatism [9]. In our study, preoperative cylinder was − 1.50 ± 0.6 (range from − 3.75 to − 1.00 D). Postoperatively, residual cylinder was − 0.43 ± 0.4 D (range from − 2 to 0). Similarly, Vestergaard et al. [3] reported that the mean cylinder magnitude was − 0.41 ± 0.34 D at 3 months after SMILE surgery. Zhang et al. declared that postoperative cylinder magnitude at the end of the 12-month follow-up was − 0.20 ± 0.27 D but the preoperative cylinder was much more lower than ours (− 0.90 ± 0.68; range from − 2.75 to − 0.25) [15].

On the other side, it is well known recently that SMILE is effective in correcting low to moderate myopic astigmatism but may be less effective when the astigmatism is mainly ocular residual astigmatism (ORA). When a certain amount of ORA exists, astigmatism of 0.5 D or less could be left uncorrected or undercorrected [14]. But we did not take into account of the cylinder magnitude's discrimination.

Effect of laterality and the location of the peripheral incision have also been researched. Ivarsen et al. [9] examined right and left eyes separately and found significant counterclockwise torsion in left eyes and no torsion in right eyes [16]. Chan et al. [6] reported that they did not find significant differences in visual and refractive outcomes of astigmatic eyes

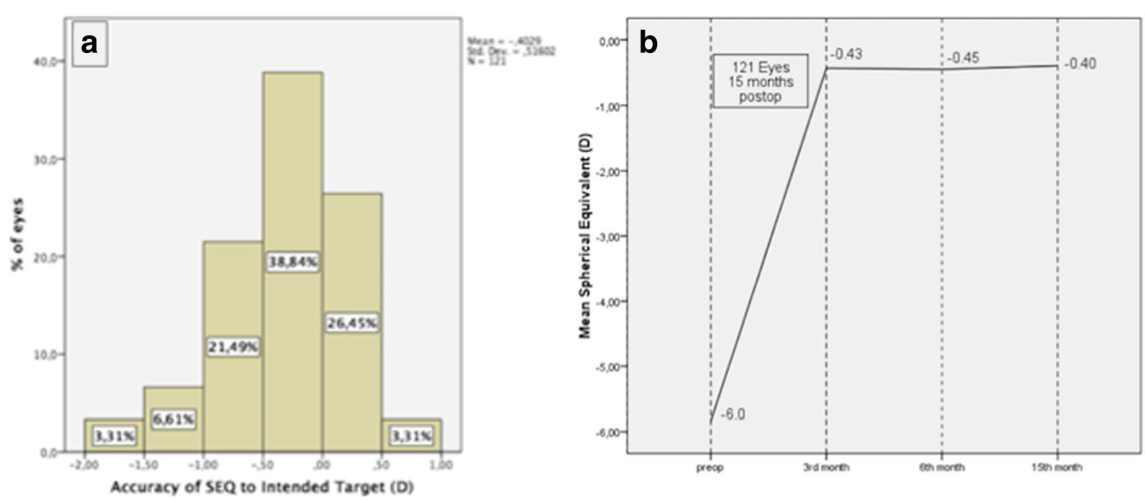


Fig. 3 **a** Postoperative spherical equivalent refraction accuracy. **b** Postoperative spherical equivalent refraction stability for 15 months

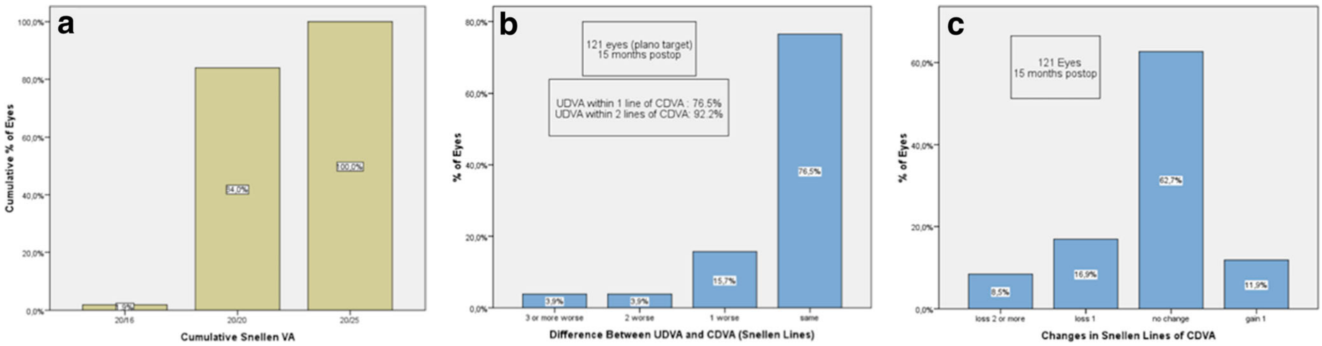


Fig. 4 **a** Postoperative cumulative Snellen uncorrected visual acuity (VA). **b** Difference between uncorrected and corrected VA. **c** Postoperative change in corrected VA

with temporal (right eyes) or superior (left eyes) opening incision during SMILE surgery based on the comparison by vector analysis and suggested that the location of opening incision in SMILE has minimal astigmatic effect.

In our study, although preoperative cylinder magnitudes were similar, postoperative cylinder was lower for left eyes with superior incision. It would not be sufficient just to compare cylinder values simply so we compared vector analysis results and found that index of success and correction index better for left eyes compared to right eyes. This result can be interpreted as that superior incision in left eyes may be concluded with better astigmatic correction than superior temporal incisions in right eyes. Because of previous reports suggesting the minimal effect of incision sites' locations [6] and emphasizing the correlation of cyclotorsion orientation with laterality [17], laterality seems to be the leading reason for this result. But further knowledge is essential to exclude the effect of opening incision's location.

There are too many studies that compare astigmatic correction effect of SMILE and femtosecond laser-assisted LASIK (FS LASIK). Liu et al. compared the results based on manifest refraction measurements and visual acuities and found similar success of two methods for correction of myopia and myopic astigmatism [18].

Zhang et al. used vector analysis for comparison and reported that both two procedures showed preferable outcomes in the correction of low to moderate astigmatism but high astigmatism was undercorrected after both [19]. In this study, TIA after SMILE was 1.75 ± 0.38 D for moderate astigmatism and SIA was 1.55 ± 0.44 in this group again. The correction index which is defined as the ratio of SIA to TIA was 0.88 ± 0.15. In high astigmatism group, correction index was 0.88 ± 0.12. In our study, SIA was 0.97 ± 0.6 D and TIA was 1.27 ± 0.6. Their ratio, the correction index was 0.78 ± 0.3, which is much more closer to undercorrection.

On the other side, Chan et al. [20] showed that SMILE offered a less favorable astigmatic correction comparable to FS LASIK in eyes with low to moderate astigmatism. Correction index was 0.93 ± 0.48 after SMILE but 1.00 ± 0.11 signifying excellent astigmatic correction for FS LASIK. Although the vector method is usually used to describe the refractive results of SMILE; lack of comparative results with FS-LASIK is a limitation of our study. Low number of eyes enrolled in the study and retrospective design are the other shortcomings. In addition, further assessment should be conducted to evaluate the correlation between astigmatism and large angle kappa and ocular residual astigmatism which might also play important roles in the treatment of astigmatism.

In conclusion, our results showed that SMILE offered favorable results with mild undercorrection for eyes with astigmatism. And left eyes have better refractive results in astigmatic correction than right eyes.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participant were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent The patient's informed consent was taken.

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