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Research Article

Laser Asymmetric Keratectomy Using a Semi-Cylindrical Ablation Pattern to Avoid Adverse Effects of Laser Refractive Surgery

Ji Sang Min[1], Byung Moo Min[2]*, Dong Cho Lee[3]

[1]Kim's Eye Hospital, Division of Cornea, Cataract and Refractive Surgery Konyang University School of Medicine, Seoul, South Korea

[2]Woori Eye Clinic, Department of Ophthalmology, Yonsei University School of Medicine, Daejon, South Korea

[3]Yeongdong Joeun Eye Clinic, Affiliated Clinical Professor to Department of Ophthalmology, Dankook University School of Medicine, Yeongdong, South Korea

***Corresponding author:** Byung Moo Min, Woori Eye Clinic, Department of Ophthalmology, Yonsei University School of Medicine, Daeduk Daero 219 (Dunsan-dong), Seo-gu, Daejon 35229, South Korea

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Abstract

Purpose: This study aimed to present a novel technique for Laser Epithelial Keratomileusis (LASEK)-Linked Laser Asymmetric Keratectomy using a Semi-Cylindrical Ablation Pattern (L-LAK-SCAP) that can prevent adverse effects following LASEK and simultaneously improve refractive errors and corneal symmetry.

Design: This is a single-center retrospective study.

Methods: We retrospectively compared the postoperative 1-year clinical results after LASEK only or L-LAK-SCAP for each group of 42 eyes of 21 patients with myopia, with a sum of deviations in the corneal thickness in four directions (SUM) on the Orbscan map of >80μm. L-LAK-SCAP simultaneously corrected the refractive error (LASEK) and myopic shift by selectively ablating thicker cornea (by LAK), thereby improving corneal symmetry and visual acuity concomitantly.

Results: The following measures were similar in both groups (p >0.05): preoperative age, Spherical Equivalent (SE), cylinder, Uncorrected Distance Visual Acuity (UDVA), pupil size, Intraocular Pressure (IOP), and corneal symmetry on Orbscan map. At 1-year postoperatively, the L-LAK-SCAP group showed better results, and the following measures differed significantly between the two groups: SE (p=0.024), UDVA (p=0.001), kappa angle (p=0.030), corneal irregularities in the 3.0mm and 5.0mm zones on the Orbscan map (p=0.033 and 0.034, respectively), SUM (p=0.000), the distance between the maximum posterior elevation (best-fit-sphere) and the visual axis (DISTANCE) (p=0.040), blurring scores (p=0.000), and myopic regression (p=0.004).

Conclusion: L-LAK-SCAP improved corneal symmetry, was associated with excellent outcomes, and may prevent adverse events following LASEK.

Keywords: Corneal symmetry; Adverse effects; LASEK; L-LAK-SCAP

Abbreviations

CCT: Central Corneal Thickness; DISTANCE: Distance between the Maximum Posterior Elevation (best-fit-sphere) and the Visual Axis; IOP: Intraocular Pressure; LAK: Laser Asymmetric Keratectomy; L-LAK-SCAP: L-LAK Semi-Cylindrical Ablation Pattern; LASEK: Refractive Error; LRS: Laser Refractive Surgery; SCAP: Semi-Cylindrical Ablation Pattern; SE: Spherical Equivalent; SUM: Sum of Deviations in the Corneal Thickness in four Directions; UDVA: Cylinder, Uncorrected Distance Visual Acuity

Introduction

Postoperative corneal changes after Laser Refractive Surgery (LRS) can result in adverse effects, such as myopic regression and ectasia, which are caused by interactions between ocular biomechanical factors [1-10]. Therefore, the next generation of LRS includes individual customization, with full integration of corneal topography, wave front sensors, and a new device to measure postoperative corneal properties that resolves asymmetric corneal thickness and curvature changes [4,5]. If regional asymmetry in corneal thickness is observed after LRS, the thinner cornea may be steepened due to reduced corneal thickness after laser ablation of the optical area caused by Intraocular Pressure (IOP), which is a risk factor for myopic regression [5-10].

Laser Asymmetric Keratectomy (LAK) features full integration with the Vision Up software, a new device designed to measure asymmetry [6]. This technique has yielded good results and the maintenance of corneal symmetry for up to 1 year in patients with SUM on the Orbscan map of >80μm [6-10]. In addition, LRS-linked LAK (LRS-LAK) yields good central symmetry, maintained at 1-year postoperatively [9]. Studies have also reported that LRS-LAK can prevent postoperative adverse effects in patients with myopia with SUM ≥80 μm [6,7,9]. In contrast, in a previous study, LRS alone yielded relatively poor surgical results, with more significant adverse effects than those of LRS with LAK in patients with myopia with SUM ≥80μm [7,9].

LAK (-SCAP) is also an effective method to correct adverse effects

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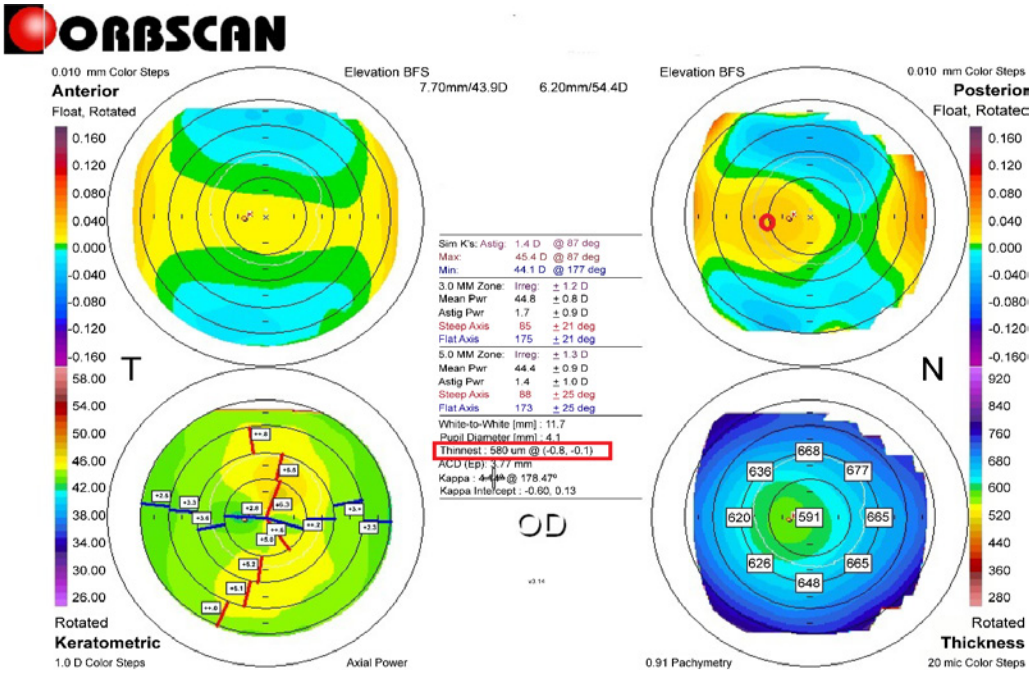

Figure 1: Preoperative pachymetric map with an example of SUM measurement.
In the case shown, the results are as follows: 0-180º, 45µm; 45-225º, 51µm; 90-270º, 20µm; and 135-315º, 29µm; total sum of deviations in the corneal thickness in four directions (SUM), 145µm. (upper right). Measuring the distance between the maximum posterior elevation (best-fit-sphere and the visual axis (DISTANCE). Corneal apex: Temporally deviated (red circle; upper right). The thinnest point (X, Y) is indicated by the lower red square.

after LRS [8,10]. To reduce corneal asymmetry, the cornea can easily be partially ablated on one side using the existing cylindrical ablation pattern [10]. To date, there have been comparative studies (LRS only *vs.* LRS-linked LAK) on patients with myopia, with SUM on the Orbscan map of >80µm and reported results of LASIK only vs. LASIK with LAK [7] or LRS (LASIK or LASEK, mixed) *vs.* LRS (LASIK or LASEK, mixed) with LAK [9]; however, there have been no reports on the results of LASEK only *vs.* LASEK with LAK.

This study aimed to present a novel technique for L-LAK-SCAP that can simultaneously improve refractive errors (myopia and astigmatism) and corneal symmetry in patients with myopia with SUM ≥80µm and compare the postoperative 1-year outcomes of LASEK only.

Patients and Methods

For this retrospective study, we evaluated 84 eyes of 42 patients with myopia treated at the Woori Eye Clinic (Daejon, South Korea) from January 2019 to April 2020. Patients underwent LASEK only (control group, 42 eyes of 21 patients) or L-LAK-SCAP (comparison group, 42 eyes of 21 patients). The study was approved by the XXX (Approval No: XXX) and was performed in accordance with the Declaration of Helsinki for research involving human subjects. Written informed consent was obtained from all patients.

The inclusion criteria were as follows: 1) Myopia with or without astigmatism; 2) SUM ≥80µm; 3) LASEK only or L-LAK-SCAP in both eyes; 4) 20-30 years old, and 5) Postoperative follow-up for at least 1-year. The exclusion criteria were as follows: 1) History of corneal disease, trauma, or ocular operations, including LRS, and 2) less than 1-year of follow-up.

Patients with refractive error underwent L-LAK-SCAP using a 193nm ISO-D200 laser (Kera Harvest Inc.; Chiayi, Taiwan). All laser corrections were performed by the same surgeon using the same method [6-10]. Local anesthesia was induced by instillation of 0.5% proparacaine hydrochloride (Alcaine, Alcon NV, Vilvoorde, Belgium). For LASEK, a 9.5mm-diameter patch of the corneal epithelium was removed with a brush. In both LASEK only and L-LAK-SCAP, laser ablation was performed for refractive correction in the 6.0-7.0 mm optic zone and in the 2.0mm transitional zone.

Correcting corneal asymmetry with LAK-SCAP

In LAK-SCAP [6-10], the Vision Up software (WellC, Hwaseong, South Korea) was used to analyze corneal thickness deviations based on corneal maps generated by Orbscan II (Bausch & Lomb, Bridgewater, NJ, USA) (Figure 1). This framework predicts the amount of ablation applied to regions of thicker cornea, the direction of the cylinder axis in degrees, the amount of ablation depth, and the myopic corneal changes due to trimming the thicker corneal area by LAK-SCAP. Figure 2 illustrates how the LAK-SCAP can be implemented with a cylindrical ablation pattern for conventional astigmatism correction. Figure 2a-2c show examples of axial, symmetric, and two-part ablation patterns, respectively. Figure 2a'-2c' show examples of one-part (semi-cylindrical) laser ablation patterns used in LAK-SCAP (Figure 3) derived from Figure 2a-2c, respectively. Figure 2d' shows the basic LAK-SCAP pattern, which is the same as one side of the ablation pattern shown in Figure 2d, and is the same as the sum of the ablation patterns of Figure 2a'-2c'.

L-LAK-SCAP ablated regions of thicker cornea selectively and simultaneously corrected the manifest refractive power (myopia and astigmatism) and myopic shift (by LAK-SCAP) with good corneal

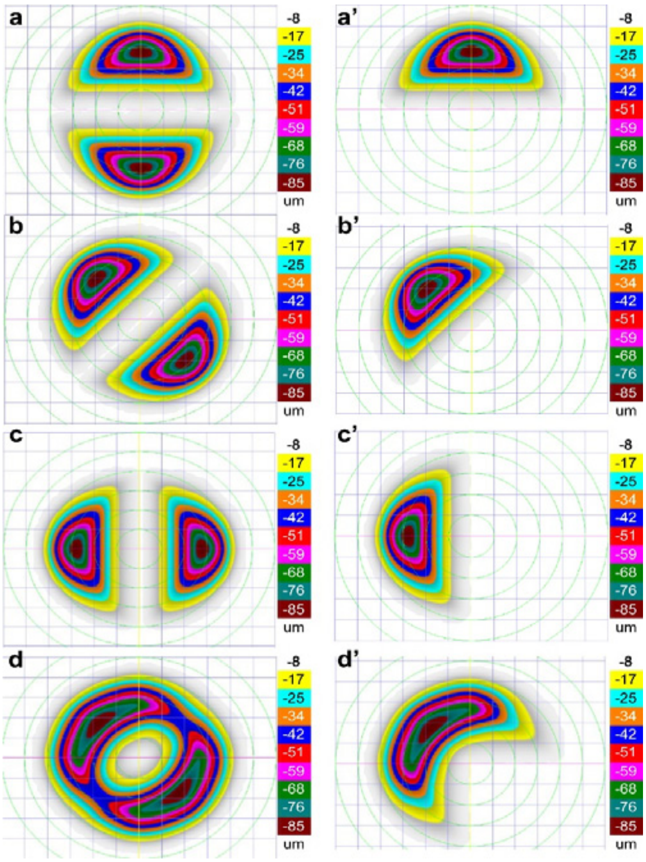

Figure 2: A schematic description of laser asymmetric keratectomy using a semi-cylindrical ablation pattern (LAK-SCAP). 2a-2c: Sample images of axially symmetric; two-part ablation patterns. 2a’-2c’: Examples of laser ablation patterns for LAK-SCAP. Specifically, they show one part of the cylindrical ablation patterns in use, as shown in parts 2a, 2b, and 2c. These patterns can be achieved by manually blocking laser corneal ablations at the thinner sections of the cornea with cotton to produce patterns of treatment similar to those shown here. 2d’, the basic LAK pattern, which is the same as one side of the axial symmetric ablation pattern shown in 2d, and the same as the sum of the ablation patterns of 2a’, 2b’, and 2c’.

symmetry (Figure 3). In the LAK-SCAP procedure, the optic zones, central corneal ablation depths, myopic shifts, and residual stromal beds were evaluated.

Follow-up

We compared the following variables between the groups preoperatively and 1-year postoperatively Spherical Equivalent (SE), cylinder, Uncorrected Distance Visual Acuity (UDVA), pupil size, IOP, kappa angle, CCT, corneal irregularities in the Orbscan 3.0mm and 5.0mm zones, SUM, and the distance between the maximum posterior elevation (best-fit-sphere) and the visual axis (DISTANCE). For each eye, we calculated the percentage of postoperative myopic regression at 1 year. Refraction was measured using cycloplegic refraction and calculated as the SE. IOP was measured using a Goldman applanation tonometer.

UDVA was measured from 6 m using the Han Chun Suk distance visual acuity chart. UDVA was converted to the logarithm of the minimum angle of resolution (LogMAR) for statistical analysis. The 1-year postoperative myopic regression during the follow-up period

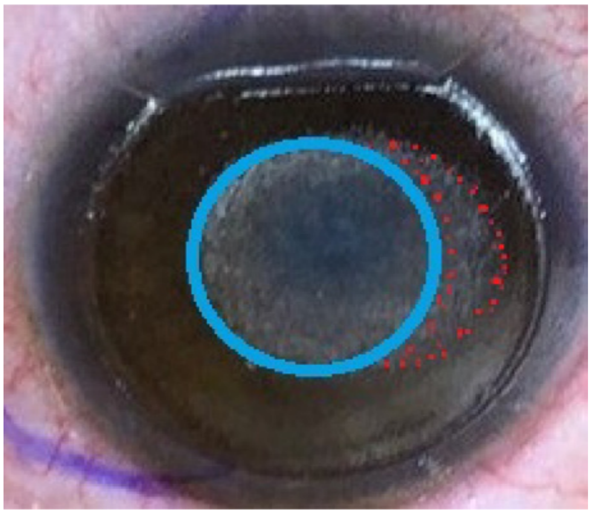

Figure 3: A representative laser ablation pattern.
A LAK-SCAP (total of -7.0 diopters) for both refractive error (red dots; -4.75 diopters) and myopic shift (blue circle; -2.25 diopters). The area enclosed in red dots indicates an asymmetric LAK-SCAP ablation pattern on a thicker area of the cornea in the peripheral region.

was defined as changes in myopia of SE ≥1.0 diopter. Preoperative and postoperative SUM and DISTANCE were analyzed using previously described methods (Figure 1, 4 and 5) [6-10].

For statistical analysis, independent-samples t-tests were performed using the IBM Statistical Package for the Social Sciences, version 18.0, IBM Corp., Armonk, NY, USA). P-values <0.05 indicated statistical significance. Data are presented as the mean ± standard deviation unless otherwise noted.

Results

Table 1 shows that the average patient ages in the control and comparison groups were 23.1 ± 5.0 and 21.5 ± 3.2 years, respectively. In these groups, the ratio of males to females was 10:11 and 9:12, respectively. The following measures were similar in both groups (p >0.05) preoperatively: SE, cylinder, UDVA, IOP, pupil size, IOP, kappa angle, CCT, corneal irregularities in the Orbscan 3.0mm and 5.0mm zones, SUM, and DISTANCE. Intraoperatively, the optic zones were 6.24 ± 0.13 mm in the control group and 6.25 ± 0.10 mm in the comparison group for myopia or astigmatism. The central ablation depth was 70.80 ± 28.15 μm in the control group and 81.93 ± 29.10 μm in the comparison group. The myopic shift due to LAK-SCAP was -1.83 ± 0.42 diopters, although it did not affect the cylinder. The residual stromal beds were 395.78 ± 38.64 μm in the control group and 389.70 ± 40.96 μm in the comparison group (Table 2).

The postoperative SE values were -0.38 ± 0.46 diopters in the control group and -0.15 ± 0.38 diopters in the comparison group (p=0.024). The postoperative cylinder values were within ±0.5 diopters in both groups. The LogMAR UDVA value was 0.09 ± 0.16 in the control group and 0.01 ± 0.04 (>20/25 in Snellen acuity) in the comparison group (p=0.001). One year postoperatively, the comparison group showed better results, and the following variables differed significantly between the groups: SE (p=0.024), UDVA (p=0.001), kappa angle (p=0.030), corneal irregularities in the 3.0mm

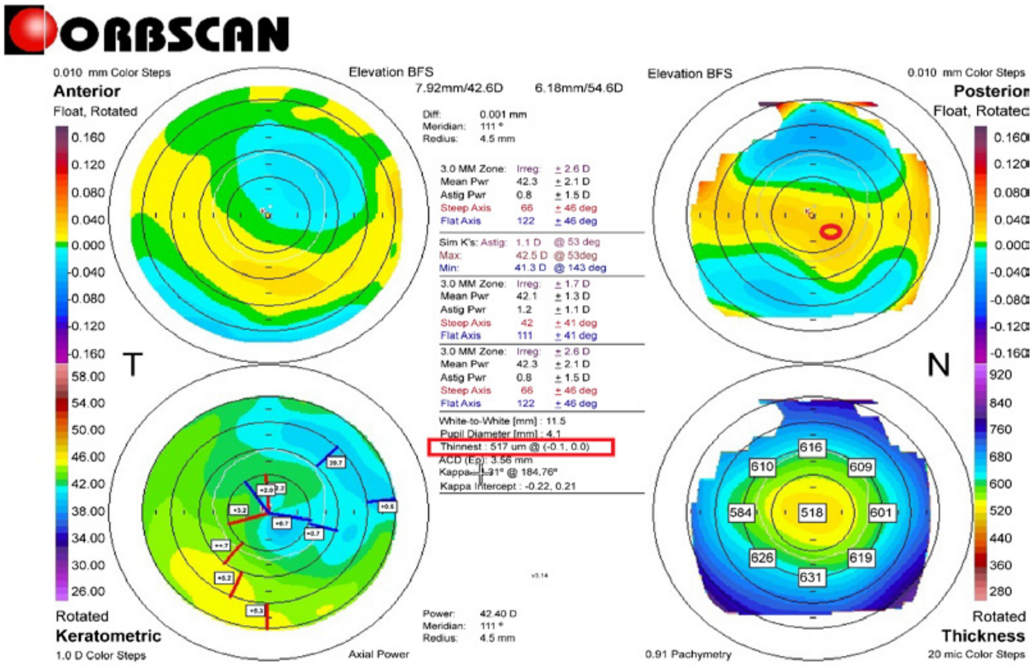

Figure 4: Postoperative pachymetric map: with same representation conventions as in Figure 1.
In the case shown, the results are: 0-180º, 17µm; 45-225, 17µm; 90-270, 15µm; and 135-315º, 9µm; total sum of deviations in the corneal thickness in four directions (SUM), 58µm. (Upper right map) Measuring the distance between the maximum posterior elevation (best-fit-sphere) and the visual axis (DISTANCE). Corneal apex: slightly inferior and nasally deviated (upper right; red circle). The thinnest point (X, Y) is indicated by the lower red box.

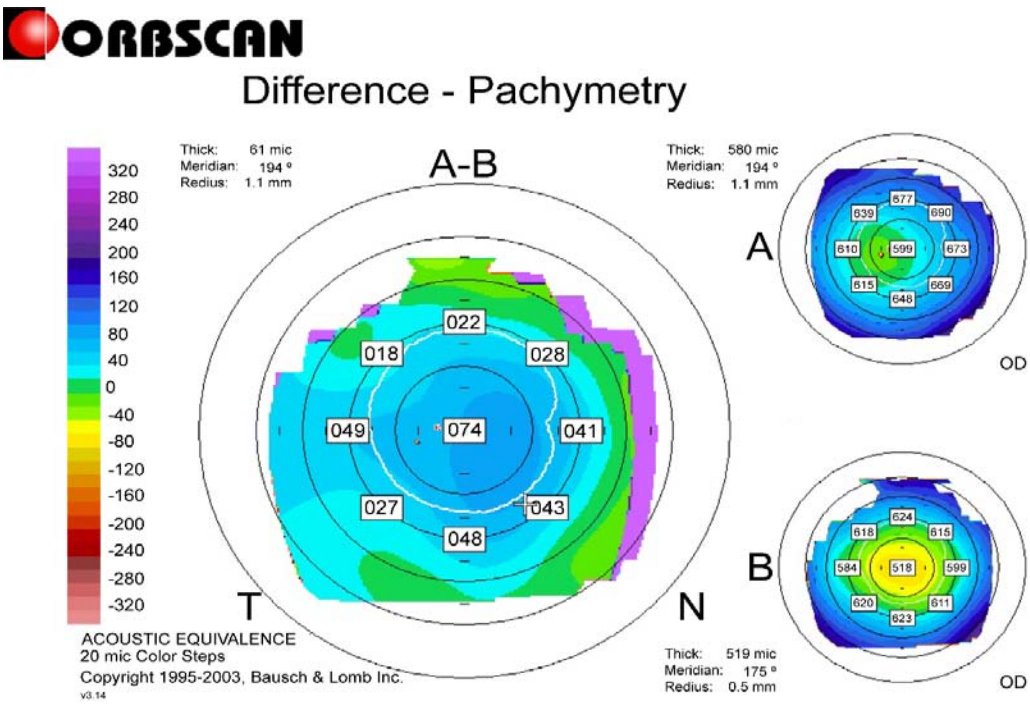

Figure 5: Differential pachymetric map comparing pre- and post-LRS-LAK-SCAP Same conventions as in Figure 1 and 4. LAK-SCAP, laser asymmetric keratectomy using a semi-cylindrical ablation pattern.

zone (p=0.033), and 5.0mm zone (p=0.034) on the Orbscan map, SUM (p=0.000), DISTANCE (p=0.040), blurring score (p=0.000), and myopic regression (p=0.004). No significant differences were observed in terms of cylinder (p=0.238), pupil size (p=0.271), IOP (p=0.802), and CCT (p=0.629) (Table 3).

Discussion

In this study, we observed no postoperative myopic regression in

Table 1: Comparison of preoperative findings between LASEK and LASEK with LAK-SCAP groups.

Outcome	Control Group (LASEK only)	Comparison Group (LASEK with LAK-SCAP)	p-value
Eyes (patients)	42 (21)	42 (21)	-
Age (years)	23.1 ± 5.0	21.5 ± 3.2	0.198
Sex (Male:Female)	10:11	9:12	0.119
SE (diopters)	-3.12 ± 1.96-	-3.37 ± 1.98	0.686
Cylinder (diopters)	0.50 ± 0.27	-0.40 ± 0.24	0.883
UDVA (LogMAR)	0.99 ± 0.07	0.99 ± 0.21	0.139
Pupil size (mm)	4.44 ± 0.66	4.42 ± 0.63	0.162
IOP (mmHg)	13.34 ± 2.34	14.24 ± 2.24	0.835
Kappa angle (degree)	4.49 ± 1.19	4.48 ± 1.56	0.807
CCT (mm)	553.22 ± 49.20	563.22 ± 49.20	0.538
Corneal irregularity in 3.0mm zone (diopters)	1.44 ± 0.37	1.51 ± 0.38	0.826
Corneal irregularity in 5.0mm zone (diopters)	1.61 ± 0.33	1.72 ± 0.38	0.853
SUM (µm)	129.61 ± 43.24	129.85 ± 38.69	0.774
DISTANCE (mm)	0.84 ± 0.37	0.84 ± 0.40	0.716

Abbreviations: SE: Spherical Equivalent; BFS: Best-Fit-Sphere; LRS: Laser Refractive Surgery; LAK: Laser Asymmetric Keratectomy; UDVA: Uncorrected Distance Visual Acuity; CCT: Central Corneal Thickness; LogMAR: Logarithm of the Minimum Angle of Resolution; corneal irregularity, corneal irregularity (diopters) in the 3.0mm zone on Orbscan maps; SUM: Sum of deviations in corneal thickness in four directions (µm); DISTANCE: Distance (mm) between the maximum posterior elevation (BFS) and the visual axis.

Table 2: Comparison of intraoperative findings (mean ± SD) between LASEK and LASEK with LAK-SCAP groups.

Item	Control group (LASEK Only)	Comparison group (LASEK with LAK-SCAP)
Optic zone (mm)	6.24 ± 0.13	6.25 ± 0.10
Central AD (µm)	70.80 ± 28.15	81.93 ± 29.10
Myopic shift due to LAK-SCAP (D)	-	-1.83 ± 0.42
RSB (µm)	395.78 ± 38.64	389.70 ± 40.96

Abbreviations: AD: Ablation Depth; D: Diopters; LAK-SCAP: Laser Asymmetric Keratectomy using Semi-Cylindrical Ablation Patterns; RSB: Residual Stromal Bed.

Table 3: Comparison of 1-year postoperative outcomes between LASEK and LASEK with LAK-SCAP groups.

Outcome	Control Group (LASEK Only)	Comparison Group (LASEK with LAK-SCAP)	p-value
Eyes (patients)	42 (21)	42 (21)	-
SE (diopters)	-0.38 ± 0.46	-0.15 ± 0.38	0.024
Cylinder	-0.40 ± 0.21	-0.39 ± 0.16	0.238
UDVA (LogMAR)	0.09 ± 0.16	0.01 ± 0.06	0.001
Pupil size (mm)	4.43 ± 0.35	4.12 ± 0.79	0.271
IOP	12.34 ± 3.30	12.34 ± 3.35	0.802
Kappa angle (degrees)	4.39 ± 1.15	3.26 ± 1.75	0.03
CCT (mm)	498.27 ± 35.37	493.15 ± 51.47	0.629
Corneal irregularity in 3.0mm zone (diopters)	2.27 ± 3.01	1.21 ± 0.34	0.033
Corneal irregularity in 5.0mm zone (diopters)	3.21 ± 0.34	2.21 ± 0.34	0.034
SUM (µm)	106.12 ± 50.44	61.45 ± 17.75	0
DISTANCE (mm)	0.81 ± 0.28	0.44 ± 0.28	0.04
Blurring score	1.24 ± 0.94	0.18 ± 0.39	0
Myopic regression, eyes (%)	5 (11.9)	0 (0)	0.004

Abbreviations: SE: Spherical Equivalent; IOP: Intraocular Pressure; BFS: Best-Fit Sphere; LRS: Laser Refractive Surgery; LAK: Laser Asymmetric Keratectomy; UDVA: Uncorrected Distance Visual Acuity; LASIK: Laser *In Situ* Keratomileusis; LASEK: Laser Epithelial Keratomileusis; CCT: Central Corneal Thickness; LogMAR: Logarithm of the Minimum Angle of Resolution; corneal irregularity, corneal irregularity in the 3.0mm and 5.0mm zones on Orbscan maps.

the comparison group, resulting in a higher success rate than in the control group, and the same as the results of LASIK with LAK [7] and LAK with LASIK or LASEK mixed [9]. Low moduli of elasticity, small optic zones, thin residual beds, and severing of the collagen lamellae with peripheral steepening and flattening of the central cornea inducing spherical aberration may be factors influencing myopic regression or blurring [1-5]. However, these factors were not applicable in the present study. When the SUM is >80μm, the cornea is made significantly thinner than its thicker area using laser ablation, and the IOP can easily cause the thinner regions to protrude locally, making the cornea steeper, leading to myopic regression postoperatively [7,11]. In this study, SUM was often markedly decreased in the comparison group. Moreover, the optic zone of LAK-SCAP treatment was 6.25mm, and the transitional zone was 2.0mm (6.0-8.5 mm from the corneal center). LAK-SCAPs ablated only thicker corneal areas, which were peripheral asymmetric corneal areas in the 8.50mm zone predicted using the Vision Up software. Therefore, an average myopic shift of -1.83 diopters was corrected. The treatment simultaneously added -3.37 diopters of sphere and -0.4 diopters of cylinder to the original refractive power. Therefore, LAK-SCAP may create central symmetry without changing the refractive power [6-10].

Moreover, we employed Orbscan maps to visualize the corneal topography rather than the current Sheimpflug techniques. DISTANCE can only be calculated on an Orbscan map because it features a central visual axis, making it useful for measuring symmetry. The Vision Up software was very useful for analyzing the corneal symmetry observed on the Orbscan II corneal maps. It predicted the target amounts of ablation for the thicker regions of the cornea, the cylindrical axis direction in degrees, the number of SCAPs, and the amount of myopic corneal change expected from the LAK-SCAP procedure. The high precision of the output led to good surgical results following L-LAK-SCAP.

The postoperative outcomes were also compared. The average postoperative SUM in the comparison group was 61.45μm, which was superior to the preoperative value (129.85μm). The DISTANCE was 0.44 on average postoperatively and 0.84 preoperatively, while preoperative and postoperative values for these variables exhibited minor changes in the control group.

LAK (-SCAP) is a relatively new technique [6-10]. Unlike previously reported techniques, such as wave front- and topography-guided LASIK or LASEK [12-15], LAK (-SCAP) reduces corneal thickness deviations via asymmetric corneal ablation. Furthermore, it increases corneal symmetry by decreasing DISTANCE. It is thereby expected to prevent corneal changes postoperatively [7-10,16-25]. An advantage of LAK (-SCAP) over LRS, which ablates the cornea symmetrically, is that it can ablate the cornea asymmetrically by selectively ablating the thick areas under predicting the plan by the Vision Up software. LRS alone yields relatively poor postoperative outcomes and adverse effects in patients with myopia presenting with SUM values ≥80μm [6-10].

Therefore, LAK-SCAP can improve corneal symmetry around the visual axis, providing better surgical results in corneas with large SUM values, thus preventing the common adverse effects of LRS. Moreover, LAK-SCAP can reduce corneal thickness deviations and can be beneficial for the following: 1) Treatment of the cornea in keratoconus [26-29], 2) Reducing corneal asymmetry [6-10], and 3) Reducing the possibilities of optical aberrations [4-15]. LAK-SCAPs may also be useful for treating corneal distortion after cataract or glaucoma surgeries, which can be problematic because they decrease IOP [22-25].

This study has several limitations. First, this was a single-center retrospective study; therefore, selection bias may exist. Second, the sample size was small. Third, the follow-up period was short. Finally, only Korean patients were included; thus, the findings may not be generalized to other ethnic groups.

Given that LAK has only recently been investigated [6-10], studies with longer follow-up (>2 years) are warranted to better investigate outcomes and adverse effects, such as myopic regression. Nonetheless, because LAK-SCAP can decrease SUM and increase corneal symmetry, it may reduce the risk of adverse effects in patients with SUM ≥80μm. Based on our findings, we recommend assessing SUM prior to LRS. Moreover, if the SUM is <80μm, conventional LRS should be acceptable; however, if the SUM is ≥80μm, LRS-LAK-SCAP is preferred.

Conclusion

Our findings indicated that L-LAK-SCAP resulted in increased corneal symmetry with good visual outcomes at 1-year postoperatively.

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