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Comparative analysis of myopia correction outcomes and aberration changes between PRK and SMILE: A study based on strict refractive criteria

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Abstract

Purpose To analyze the refractive outcomes and changes in corneal aberrations after PRK and SMILE surgeries, and to compare these two methods.

Patients and methods This retrospective comparative study investigated patients aged 20–40 years who underwent SMILE or PRK for the correction of myopia between − 1.00 D and − 2.00 D, along with a cylindrical power of -0.50 D or lower. Preoperative and 6-month postoperative assessments included uncorrected visual acuity (UCVA), best-corrected visual acuity (BCVA), and corneal aberrations such as higher-order aberrations (HOA), spherical aberrations (SA), vertical coma (Z3,-1), horizontal coma (Z3,1), oblique trefoil (Z3,-3), and horizontal trefoil (Z3,3).

Results A total of 73 eyes from 73 patients (37 SMILE and 36 PRK) were analysed. Both groups showed significant improvement in UCVA and refractive parameters ($p < 0.05$), while BCVA remained stable ($p > 0.05$). Postoperative corneal aberrations increased in both groups, with no significant intergroup differences ($p > 0.05$).

Conclusions Both SMILE and PRK are effective and safe for the correction of low myopia, with comparable refractive outcomes and visual quality. Despite an increase in corneal aberrations in both techniques, their impact on overall visual performance is similar. Procedure selection should be individualized based on patient-specific factors and lifestyle.

Keywords Low myopia, SMILE, PRK, Corneal aberrations, Refractive surgery

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Introduction

Refractive errors are the leading cause of visual impairment and the second leading cause of vision loss globally, with their prevalence projected to rise sharply in the coming decades [1]. Among these errors, myopia is the most common condition [2]. While temporary solutions such as glasses and contact lenses are widely used, advancements in refractive laser surgery now allow for permanent correction [3]. This progress has led to the increasing adoption of procedures such as Photorefractive Keratectomy (PRK) and Small Incision Lenticule Extraction (SMILE), which have become prominent in clinical practice [4, 5].

PRK employs advanced surface ablation technology to reshape the cornea using an excimer laser, while SMILE is recognized for its flapless, minimally invasive approach that involves removing a corneal lenticule [6, 7]. Both techniques offer distinct approaches to achieving significant improvements in visual acuity and refractive outcomes. However, postoperative aberrations—deviations from ideal optical properties—are critical factors to consider alongside visual acuity when evaluating overall visual outcomes and patient satisfaction. These postoperative aberrations, which arise from corneal shape changes involving central flattening and peripheral steepening, are anticipated to be less pronounced in cases of low myopia correction [8].

To the best of our knowledge, this study is the first to investigate the refractive outcomes and changes in corneal aberrations for PRK and SMILE surgeries performed to correct myopia of 2 diopters or less, and to compare these two methods.

Methods

This retrospective comparative study was conducted in accordance with the tenets of the Declaration of Helsinki and received ethical approval from the Ethics Committee of Kayseri City Training and Research Hospital, with approval code 271/2024. The study included patients who had previously undergone SMILE or PRK between January 2023 and March 2024. All procedures were performed at the Department of Ophthalmology, Kayseri Mayagöz Hospital, Turkey.

Patient Selection.

Patient records were retrospectively reviewed to identify individuals who met the study's inclusion and exclusion criteria. Eligible patients were those aged between 20 and 40 years, with a spherical error ranging from – 1.00 D to -2.00 D and a cylindrical power of ≤ -0.50 D. A key inclusion criterion was a preoperative corrected distance visual acuity (CDVA) of 0.0 LogMAR (equivalent to 20/20 vision) or better. Additionally, the residual corneal stromal bed thickness had to be at least 280 µm for the SMILE group and 350 µm for the PRK group. Patients were excluded if they had a corneal thickness below 480 µm, a refractive change exceeding 0.5 D in the previous year, or corneal pathologies such as keratoconus or pellucid marginal degeneration. Furthermore, patients who had worn contact lenses within the week prior to surgery were also excluded. Participants with a history of eye trauma, previous ocular surgeries, or systemic conditions, including collagen tissue disorders, diabetes, rheumatological diseases, or metabolic disorders, were also excluded from the study. If both eyes of the patient met the inclusion criteria, the right eye was selected for the study. If only one eye met the inclusion criteria, that eye was included in the study.

Ophthalmic examination and measurements

All patients underwent comprehensive preoperative and postoperative ophthalmic evaluations, including slit-lamp biomicroscopy, dilated fundus examination, manifest and cycloplegic refraction, and assessments of uncorrected and corrected visual acuity using the Snellen chart. Intraocular pressure was measured using non-contact tonometry, while tear function was assessed through the Schirmer test and tear break-up time. Corneal topography and corrneal aberrometry with a 6.0 mm pupil scan size were performed using the Pentacam system (Oculus, Wetzlar, Germany). Key parameters analyzed included total higher-order aberrations (HOA), 4th-order spherical aberrations (SA), vertical coma (Z3,-1), horizontal coma (Z3,1), oblique trefoil (Z3,-3), and horizontal trefoil (Z3,3).

Surgical techniques

The SMILE procedure was performed using the 500-kHz VisuMax femtosecond laser system (Carl Zeiss Meditec, Jena, Germany). A 6.5 mm optical zone was selected for each patient, and a side-cut incision was created at 120 degrees with a width of 2.4 mm to access the lenticule. The laser energy was set at 160 nJ, and the lenticule was created at a cap thickness of 120 µm. After the formation of the lenticule, it was manually dissected with a blunt spatula and extracted through the small incision without lifting a corneal flap. To account for potential regression, an additional 10% correction was programmed for the entered values of myopia and astigmatism.

For PRK, the corneal epithelium was removed using a 20% alcohol solution applied to an 8 mm treatment area for 20 s. The epithelium was then gently removed with a blunt spatula, and the stromal bed was rinsed thoroughly with a balanced salt solution to eliminate any residual alcohol. Stromal ablation was performed using an excimer laser (Alcon Wavelight® EX500, Alcon Laboratories, Fort Worth, TX, USA) with a programmed 6.5 mm optical zone. The ablation depth and diameter were customized for each patient based on the preoperative

manifest refraction. During the PRK procedure, a spherical overcorrection of 0.25 D was programmed, while the cylindrical value was left unchanged. At the completion of the procedure, a bandage contact lens was placed on the cornea and kept in place for approximately 3 to 5 days, depending on the epithelial healing process.

Postoperative care

After the SMILE procedure, patients were prescribed a topical antibiotic, moxifloxacin 0.5% (VIGAMOX, Alcon Laboratories, Inc., Fort Worth, TX), four times a day for one week to prevent infection. Additionally, a corticosteroid eye drop, fluorometholone 0.1% (FML, Allergan, Irvine, CA, USA), was prescribed four times a day for the first week, followed by a gradual tapering over the next three weeks. Artificial tears were recommended for all patients as needed to relieve postoperative dryness.

For PRK, similar postoperative care was provided, with a topical antibiotic (moxifloxacin 0.5%) prescribed four times a day until the bandage contact lens was removed. A corticosteroid eye drop (fluorometholone 0.1%) was initiated four times a day once the epithelial defect had healed, typically within 3 to 5 days, and was tapered gradually over four weeks. Additionally, artificial tears were recommended to manage dryness, which is common following surface ablation procedures.

All patients were scheduled for follow-up visits at 1 day, 1 week, 1 month, 3 months, and 6 months postoperatively. During these visits, slit-lamp examination, visual acuity measurements, and intraocular pressure assessments were performed to monitor healing and detect any complications. Corneal topography and aberrometry were repeated at 6 months postoperatively to evaluate refractive stability and changes in corneal aberrations.

Table 1 Baseline characteristics of eyes in both groups

	SMILE	PRK	*P**
Age (y)	24.81 ± 2.16 (21, 30)	24.53 ± 2.47 (20, 28)	0.603
Gender (M/F)*	18/19	18/18	0.908
Refractive error (D)			
Sphere	− 1.66 ± 0.33 (− 2.00, 0)	− 1.55 ± 0.31 (− 2.00, 0)	0.158
Cylinder	− 0.32 ± 0.20 (− 0.50, 0)	− 0.31 ± 0.21 (− 0.50, 0)	0.698
UDVA (logMAR)	0.63 ± 0.14 (0.30, 0.87)	0.61 ± 0.18 (0.30, 1.00)	0.337
CDVA (logMAR)	− 0.04 ± 0.06 (− 0.18, 0)	− 0.04 ± 0.05 (− 0.18, 0)	0.575

Data shown as mean values ± standard deviation (minimum-maximum)

SMILE small incision lenticule extraction, *PRK* photorefractive keratectomy, *D* diopters; *UDVA* uncorrected distance visual acuity, *CDVA* corrected distance visual acuity, *logMAR* logarithm of the minimum angle of resolution

*Between-group differences assessed by Independent samples t test; Gender difference between-group assessed by chi-square test

Statistical analysis

Data were analyzed using SPSS software for Windows, version 30.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were presented as mean ± standard deviation (SD). The Shapiro-Wilk test was used to assess the normality of the data distribution. For comparisons of normally distributed data between two groups, the Student's t-test was employed. To compare preoperative and postoperative data within each group, the paired Student's t-test was applied. For non-normally distributed data, the Wilcoxon and Mann Whitney U test were utilized. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 73 eyes from 73 patients were included in the study. The SMILE group comprised 37 patients (19 males, 18 females), while the PRK group consisted of 36 patients (17 males, 19 females). The mean age of the SMILE group was 24.81 ± 0.37 years, and the mean age of the PRK group was 24.53 ± 0.41 years. The demographic characteristics and preoperative parameters of the patients are summarized in Table 1. The preoperative Q values were − 0.33 ± 0.16 for the SMILE group and − 0.38 ± 0.12 for the PRK group, with no statistically significant difference observed between the groups ($p = 0.193$). Postoperative Q values for the SMILE group were − 0.13 ± 0.17, while for the PRK group, they were − 0.19 ± 0.13. No statistically significant difference in Q values was found between the two groups postoperatively($p = 0.079$).

Visual and refractive outcomes

When comparing preoperative and 6-month postoperative values, a statistically significant improvement was observed in spherical values, cylindrical values, and uncorrected visual acuity (UCVA) within each group ($p < 0.05$). However, the change in best-corrected visual acuity (BCVA) was not statistically significant in either group ($p > 0.05$). In terms of 6-month postoperative uncorrected distance visual acuity (UDVA) values, 81.08% of patients in the SMILE group (30 out of 37) achieved a logMAR value of 0.0. In addition, 13.51% (5 out of 37) demonstrated a logMAR of -0.1, and 5.41% (2 patients) recorded a logMAR of -0.2. In comparison, the PRK group showed that 83.34% of patients (30 out of 36) reached a logMAR of 0.0, while 13.89% (5 out of 36) had a logMAR of -0.1, and 2.78% (1 patient) exhibited a logMAR of -0.2. Postoperative UDVA values were similar between the two groups ($p = 0.772$).

The postoperative spherical equivalent for the SMILE group was 0.23 ± 0.17 D, while the PRK group recorded a value of 0.35 ± 0.15 D. No significant difference was observed between the two groups ($p = 0.767$). Similarly, the postoperative spherical power was 0.11 ± 0.17 D for

Table 2 Changes in corneal HOAs after SMILE and PRK

	Preoperative			6 months		
	SMILE	**PRK**	***P***	**SMILE**	**PRK**	***P***
Total HOAs	0.36 ± 0.09	0.35 ± 0.07	0.665	0.40 ± 0.10	0.40 ± 0.08	0.888
Vertical coma	-0.07 ± 0.16	-0.09 ± 0.14	0.641	-0.08 ± 0.19	-0.08 ± 0.20	0.945
Horizontal coma	-0.04 ± 0.12	-0.06 ± 0.12	0.610	-0.05 ± 0.14	-0.07 ± 0.13	0.508
Horizontal trefoil	0.03 ± 0.08	0.04 ± 0.08	0.391	0.02 ± 0.08	0.07 ± 0.29	0.373
Spherical aberration	0.20 ± 0.07	0.19 ± 0.06	0.554	0.23 ± 0.09	0.22 ± 0.07	0.547
Oblique trefoil	-0.04 ± 0.10	-0.01 ± 0.12	0.250	-0.04 ± 0.11	-0.03 ± 0.24	0.721

HOAs higher-order aberrations, *SMILE* small incision lenticule extraction, *PRK* Photorefractive keratectomy

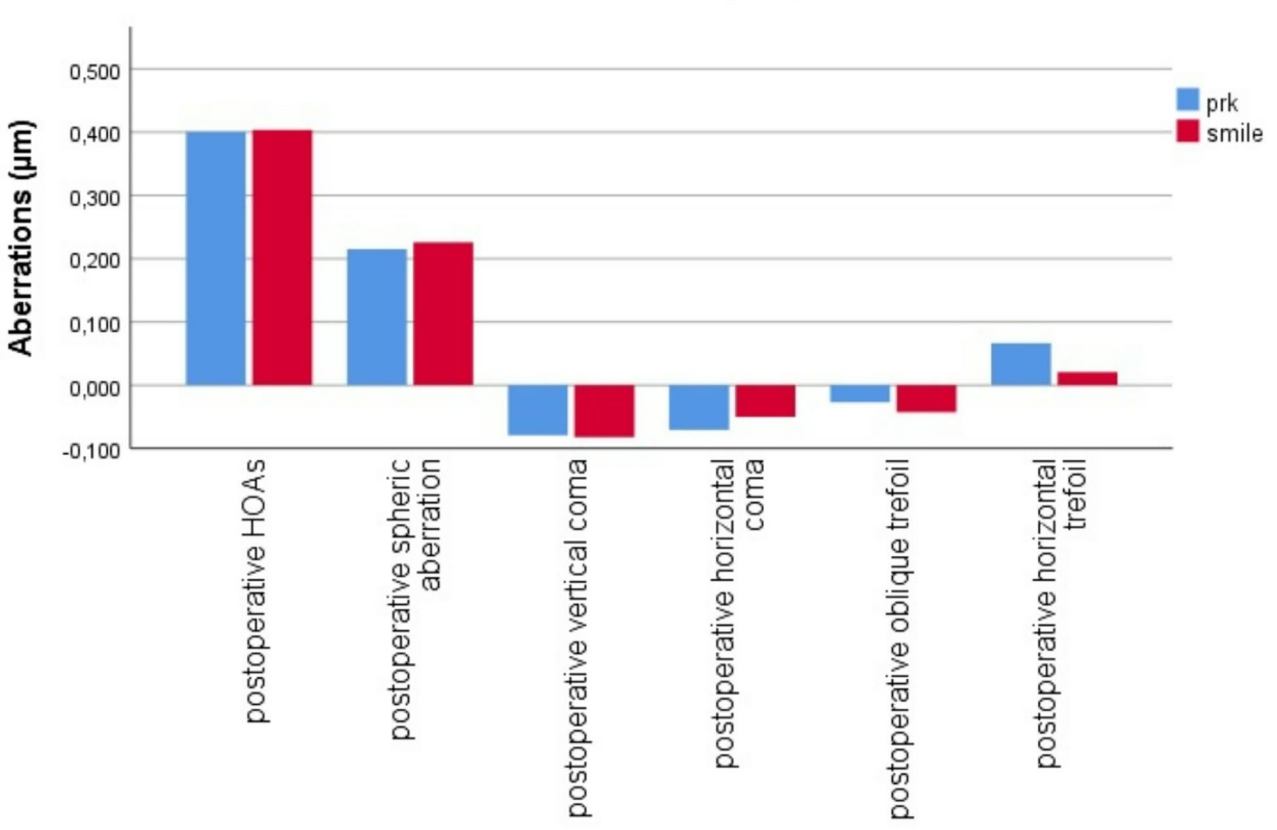

Fig. 1 Corneal aberrations in the SMILE (small incision lenticule extraction) and PRK (photorefractive keratectomy) groups

the SMILE group and 0.12 ± 0.16 D for the PRK group, again showing no statistically significant difference ($p = 0.669$). Furthermore, the cylinder power values were − 0.17 ± 0.17 D in the SMILE group and − 0.18 ± 0.16 D in the PRK group, with no difference noted between the groups ($p = 0.766$).

Corneal Aberrations

Postoperative assessments of corneal aberrations revealed a significant increase in HOA, spherical aberrations (SA), vertical coma (Z3,-1), horizontal coma (Z3,1), oblique trefoil (Z3,-3), and horizontal trefoil (Z3,3) in both groups ($p < 0.05$). Despite these increases, there was no statistically significant difference between the SMILE and PRK groups in terms of postoperative corneal aberrations ($p > 0.05$). (Table 2) (Fig. 1).

Discussion

The results of this study demonstrate that both SMILE and PRK are effective surgical techniques for the correction of low myopia, yielding comparable visual and refractive outcomes. However, each technique presents unique benefits and limitations, which are essential to consider when selecting the most appropriate procedure for individual patients.

One notable advantage of SMILE is its minimally invasive nature, which avoids the creation of a corneal flap. This reduces the risk of flap-related complications, such as dislocation or epithelial ingrowth, which are potential

issues in flap-based procedures like LASIK [9]. Additionally, the small incision in SMILE helps preserve corneal biomechanics, potentially reducing the risk of postoperative ectasia in the long term [10]. Furthermore, studies have shown that SMILE is associated with a faster recovery of corneal sensitivity and tear function due to the preservation of anterior corneal nerves, enhancing patient comfort and satisfaction [11, 12]. These findings align with those reported by Ganesh et al., where SMILE was shown to have superior contrast sensitivity and lower HOA induction compared to PRK in cases of low myopia [13].

In contrast, PRK is a viable option, particularly for patients with thinner corneas or those at higher risk of trauma due to lifestyle or occupational factors [14]. PRK eliminates the need for a corneal flap by employing a surface ablation technique, making it a safer option for patients with specific contraindications for flap-based procedures [15]. However, PRK is associated with a longer recovery period and greater discomfort, as the epithelial layer regenerates over several days. This prolonged healing period can lead to fluctuating vision and potential dissatisfaction during the early postoperative phase [14]. Another concern with PRK is the increased risk of corneal haze, especially in cases requiring deeper ablations. This risk was managed in our study with the use of mitomycin-C, which has been shown to reduce the incidence of haze formation effectively [16]. In our study, it was observed that no lines were lost in CDVA, and no corneal haze was detected in the PRK group. Comparing SMILE and PRK for the correction of low myopia and astigmatism, Ganesh et al. reported that four eyes in the PRK group suffered a one-line decrease in CDVA because of corneal haze, although the SMILE group experienced no decrease in CDVA, indicating a superior safety profile with SMILE [13]. Given that high myopia increases the risk of corneal haze formation [17], our decision to include only patients with less than 2 D myopia instead of 4 D myopia as inclusion criteria may have contributed to this outcome.

Regarding corneal aberrations, both SMILE and PRK resulted in significant increases in HOAs. This finding is consistent with previous studies indicating that refractive surgery, regardless of the technique used, can induce HOAs due to changes in corneal shape and curvature [18]. In this study, specific increases were noted in spherical aberration, vertical and horizontal coma, and trefoil in both groups. However, the lack of a statistically significant difference between the two groups in terms of HOAs suggests that both techniques similarly impact optical quality in low myopia cases. These results are consistent with the findings of Fu et al., who reported that SMILE induced less spherical aberration, but greater vertical coma compared to LASEK [19]. In another study, Zhang et al. found that SMILE induced higher levels of coma and total HOAs compared to PRK, indicating a comparable impact on optical quality [20]. According to Sarkar et al., six months after PRK surgery, the mean HORMS (root mean square of the third to eighth radial order Zernike coefficients) was higher than after SMILE surgery [21]. They hypothesized that as the epithelium heals after PRK, the corneal surface becomes irregular, leading to an increase in higher order aberrations that degrade image quality. In contrast, SMILE surgery maintains the corneal surface largely intact, resulting in a relatively smaller increase in higher order aberrations. However, comparing the results between SMILE and transepithelial PRK at 3 months, Zheng et al. found significantly higher levels of coma and total HOAs after SMILE compared to transepithelial PRK. They attributed this result to the use of a monitoring system for cyclotorsion and motion compensation in PRK and the absence of this system in SMILE [8]. Another study conducted by Yıldırım et al. revealed that there were no significant statistical differences between SMILE and PRK in terms of inducing coma, spherical, and trefoil aberrations. However, the total higher order aberrations were significantly higher after SMILE compared to PRK [22]. Unlike the aforementioned studies, no significant difference was found in the current study in terms of higher order deviations, including spherical deviation, horizontal coma, vertical coma, oblique trefoil and horizontal trefoil.

There have been several studies that evaluated the visual and refractive outcomes of patients who underwent PRK and SMILE surgery, concluding that both methods are effective and safe [13, 19, 23]. Our study was in line with these findings, as all eyes reached a UDVA of 20/20 or better, regardless of the surgical method used. In the study by Reinstein et al., 96% of eyes undergoing SMILE surgery had uncorrected distance visual acuity of 20/20 or better [23], while Fu et al. reported 97% [19]. Although both studies similarly evaluated refractive surgery outcomes for low myopia, our remarkable result may be attributed to our more stringent inclusion criteria of a preoperative low cylindrical and spherical power. When patients with low preoperative cylinder power were selected, the results were not surprising, as all eyes in the SMILE group achieved UDVA of 20/20 or better, compared to 97% in the PRK group [13]. The SMILE surgical platform does not include a cyclotorsional compensation system, and with higher preoperative astigmatism, like 3 D, a 10° cyclotorsion could result in approximately 1 D of residual astigmatism [24]. In fact, when comparing SMILE to femtosecond LASIK, the SMILE group showed a significantly higher absolute angle of error, with values of 22° versus 12° [25]. In contrast, Jun et al. found that both SMILE and PRK yielded comparable visual and refractive outcomes, even in cases of myopia with high

astigmatism. They explained this by the fact that their use of triple centration to establish references in both the horizontal and vertical meridians facilitated the correction of astigmatism [26]. Here, we reported that the mean cylindrical power was − 0.18 D in the PRK group and − 0.17 D in the SMILE group, showing no significant difference between the two groups.

Myopic regression, which is known to be inversely correlated with the degree of preoperative myopia [27], is one of the most common postoperative complications for both SMILE and PRK. Therefore, some adjustments in treatment planning, such as overcorrection, have been evaluated in many studies. A study found that overcorrection was notably more effective in eyes with low myopia compared to those with high myopia, suggesting that the degree of myopia may influence the efficacy of overcorrection as a treatment strategy [28]. However, studies have shown that after PRK, a higher percentage of eyes with low myopia maintain a refractive outcome within ± 1.00 dioptre of emmetropia than eyes with moderate or high myopia [27, 29]. In the study conducted by Ramin et al., overcorrections after PRK varied by participant age, ranging from 0.75 diopters (D) for individuals aged 18–20 years to no overcorrection for those aged 36–50 years [28]. In contrast, the impact of age on the risk of myopic regression remains a debated issue in predicting refractive outcome stability. In our study, we applied a consistent overcorrection of 0.25 diopters (D) for all patients undergoing PRK to attain the target refractive results, regardless of the patients' age.

Regarding refractive stability after SMILE, Reinstein et al. recommended overcorrection and observed that the postoperative spherical equivalent was − 0.05 ± 0.36 diopters (D) [23]. The study evaluating PRK and SMILE in the correction of low myopia used a 10% overcorrection nomogram for both spherical and cylindrical components and showed that there was no significant difference in mean residual spherical equivalent between the groups at 3 months postoperatively [13]. We targeted mild hyperopia as 0.25D and found that the postoperative spherical equivalent was 0.03 in the SMILE group and 0.03 in the PRK group, with no difference between the groups.

This study's main strength lies in its focus on low myopia correction (≤ 2 D), an area that has been relatively underexplored in previous comparative studies. By limiting the degree of myopia, we were able to obtain a clearer understanding of the refractive outcomes and aberration profiles associated with each technique. However, the relatively short follow-up period of six months may not fully capture long-term stability or potential late-onset complications, such as regression or haze formation. Additionally, the retrospective design and small sample size limit the generalizability of our findings. Future studies with larger sample sizes and longer follow-up periods are needed to validate these results and explore additional parameters, such as patient-reported outcomes and quality of life.

In conclusion, both SMILE and PRK are effective options for the correction of low myopia, each offering specific advantages depending on patient and procedural factors. Although both procedures lead to an increase in higher-order aberrations, their impact on visual quality appears to be similar. Ultimately, the choice of technique should be individualized based on the patient's anatomical characteristics, visual expectations, and lifestyle needs.

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Author contributions
BK, MEA wrote the main manuscript text; BK, MEA did statistical analysis; MEA, ES prepared tables and figure. All authors reviewed the manuscript.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request".

Declarations

Ethics approval and consent to participate
The study followed the tenets of the Declaration of Helsinki and was approved by the local ethics committee. All participants received both oral and written information about the study, and each participant provided his or her written informed consent.

Competing interests
The authors declare no competing interests.

Consent for publication
Not Applicable.

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