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REFRACTIVE SURGERY

Evaluation of disk halo size after small incision lenticule extraction (SMILE)

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Abstract

Purpose To investigate changes in objective disk halo size produced by a glare source after small incision lenticule extraction (SMILE) for myopia correction.

Methods This prospective clinical study included 45 right eyes of 45 patients with a mean age of 25.40 ± 5.06 years and mean spherical equivalent (SE) of −6.08 ± 1.90 diopters. Disk halo size was measured with a vision monitor before surgery and at postoperative 1 week and 3 months. Other information was collected, including age, SE, lenticule thickness, lenticule diameter, dark pupil, and pupillary response to light parameters (initial diameter; amplitude, latency, duration, and velocity of contraction; latency, duration, and velocity of dilation; and maximum, minimum, and average pupil size).

Results Compared to preoperative values, disk halo size increased significantly at postoperative 1 week ($P = 0.026$) and returned to baseline at postoperative 3 months ($P = 0.349$). Preoperative disk halo size significantly correlated with SE ($r = -0.346$, $P = 0.020$), minimum pupil size ($r = 0.365$, $P = 0.014$), and average pupil size ($r = 0.310$, $P = 0.038$). Disk halo size at postoperative 1 week was significantly correlated with age ($r = 0.324$, $P = 0.030$) and minimum pupil size ($r = 0.297$, $P = 0.047$). Disk halo size at postoperative 3 months was significantly correlated with lenticule diameter ($r = -0.362$, $P = 0.015$), initial diameter ($r = 0.311$, $P = 0.037$), maximum pupil size ($r = 0.312$, $P = 0.037$), minimum pupil size ($r = 0.440$, $P = 0.002$), and average pupil size ($r = 0.373$, $P = 0.012$).

Conclusions After SMILE, disk halo size demonstrated a temporary increase and then returned to baseline.

Keywords Small incision lenticule extraction (SMILE) · Disk halo size · Pupillary light response · Glare

Introduction

Light from a bright light source entering the retina is diffused by the various optical elements of the eye. The diffused light creates a veil over the back of the retina which can lead to a loss in contrast and details of an object. The phenomenon is referred to as disability glare, and the veil is known as disk halos [1, 2]. Glare and halos are common complaints after refractive surgery that require special attention, especially after corneal refractive surgery. In many patient satisfaction surveys after corneal refractive surgery, glare and halos are the main complaints [3–7].

Small incision lenticule extraction (SMILE) benefits from the well-developed femtosecond laser technology and exhibits many advantages over traditional laser in situ keratomileusis (LASIK). For example, it can avoid the flap-related complications encountered in LASIK surgery and reduce corneal nerve damage, thereby alleviating postoperative dry eye symptoms and maintaining corneal sensitivity [8–10]. Many studies have confirmed the safety and stability of SMILE surgery for myopia correction [11, 12].

Considering that glare and halos remain common problems after SMILE surgery [13], changes in glare and halos after

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SMILE surgery require further studies. Previous investigations have shown changes in glare after SMILE using a double-pass optical quality analysis system (OQAS) [14] or a straylight meter (C-Quant) [15]. To the best of our knowledge, however, no study has focused on halo size measurements in relation to SMILE surgery.

Here, we analyzed correlations between disk halo size produced by a glare source and pupillary light response parameters, in order to understand disk halo size after SMILE and determine its influencing factors.

Methods

This study was approved by the Ethics Committee of the Eye and ENT Hospital of Fudan University and complied with the Declaration of Helsinki. Informed written consent was obtained from all patients after the possible consequences of the study were explained.

Study population

Consecutive patients were enrolled in this prospective study. All patients underwent routine preoperative ophthalmic examinations at the Refractive Surgery Center in the Department of Ophthalmology of the Eye and ENT Hospital of Fudan University.

The inclusion criteria were as follows: patients aged between 18 and 35 years, spherical equivalent (SE) up to −9.5 diopters (D), corrected distance visual acuity (CDVA) of 20/20 or better, and stable refraction for 2 years. Because age has relationships with both the pupillary response to light and disk halo size [16], and patients between 20 and 50 years of age have similar disk halo sizes [17], the inclusion age range was modified to 18–35 years.

The exclusion criteria were as follows: systemic diseases, a history of ocular surgery or trauma, and a history of ocular disease other than myopia or astigmatism.

Data from the right eye of each patient were selected for statistical analysis.

Surgical procedure

The same surgeon (Dr. Zhou) performed all surgical procedures. In the SMILE procedures, a 500-kHz VisuMax femtosecond laser system (Carl Zeiss Meditec, Jena, Germany) was used, with a pulse energy of 130 nJ. The lenticule diameter was set between 6.25 and 6.70 mm; the cap diameter was set to 7.5 mm at a 120-μm depth. A 90° single-side cut, with a length of 2 mm, was created to remove the lenticule. Topical levofloxacin, 0.1% fluorometholone solution, and non-preserved artificial tears were used after the surgery.

Measurements

Disk halo size and pupillary light response were evaluated by an experienced technician before surgery, and at postoperative 1 week and 3 months with monocular dynamic pupillometry (MonCv3; Metrovision, Pérenchies, France).

As described in previous studies [17, 18], all measurements were obtained between 9:00 a.m. and 11:30 a.m. after 5 min of darkness adaptation. A light source on the right side was used to test the right eye with a luminance of 5 cd/m^2. The refractive error was fully corrected with a lens before surgery. Because all patients had worn glasses before SMILE, we presume that our measurements approximate situations in their daily lives. There were three radial lines of 10 letters appearing from the periphery toward the light source on the screen such that 10 letters formed 10 rings at 30-min arc intervals (arcmin). The average distance to the letter nearest to the light source was measured for each line, and then the visual angle formed by the radius of the halo was calculated in arcmin (Fig. 1).

The pupillary contour was automatically traced by the pupillometer with an accuracy of ± 0.1 mm after 5 min of darkness adaptation. Then, the software performed an analysis of responses to successive visual stimuli with automated quantification of the following parameters: initial diameter; amplitude, latency, duration, and velocity of contraction; latency,

Fig. 1 The operative interface of the vision monitor

duration, and velocity of dilation; and maximum, minimum, and average pupil sizes. Each parameter was measured at least five times and the mean values were recorded.

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) (version 22; IBM, Armonk, NY, USA). All data were tested for normality using the Kolmogorov-Smirnov test. The Friedman test with a Bonferroni correction was performed to evaluate changes in disk halo size over time. Pearson's and Spearman's correlation analyses were applied to detect potential correlations between disk halo size and other parameters. A P value less than 0.05 was considered statistically significant.

Results

Forty-five patients with a mean age of 25.40 ± 5.06 years (range 18 to 35 years) and mean SE of − 6.08 ± 1.90 D (range − 3.50 to − 8.75 D) were enrolled. Table 1 shows the demographic and refractive data. All surgeries were uneventful, and no intraoperative or postoperative complications were observed. No patient was lost to follow-up in this study.

Compared to preoperative values (166.22 ± 61.29), disk halo size increased significantly at postoperative 1 week (187.78 ± 39.88) (P = 0.026) and returned to baseline at postoperative 3 months (160.22 ± 64.75) (P = 0.349) (Fig. 2).

Table 1 Demographic and refractive data (n = 45)

Parameters	Mean	SD
Age (years)	25.40	5.06
Sphere (D)	− 5.60	1.82
Cylinder (D)	− 0.96	0.85
SE (D)	− 6.08	1.90
Lenticule diameter (mm)	6.58	0.21
Lenticule thickness (um)	113.13	28.96
Dark pupil (mm)	7.06	0.65
Initial diameter (mm)	5.33	0.64
Amplitude of contraction (mm)	1.83	0.29
Latency of contraction (ms)	239.09	64.68
Duration of contraction (ms)	647.09	75.87
Velocity of contraction (mm/s)	5.81	0.88
Latency of dilation (ms)	886.29	60.78
Duration of dilation (ms)	1574.76	73.08
Velocity of dilation (mm/s)	2.34	0.48
Maximum pupil (mm)	5.93	0.64
Minimum pupil (mm)	3.43	0.44
Average pupil (mm)	4.82	0.54

D diopters, *SE* spherical equivalent

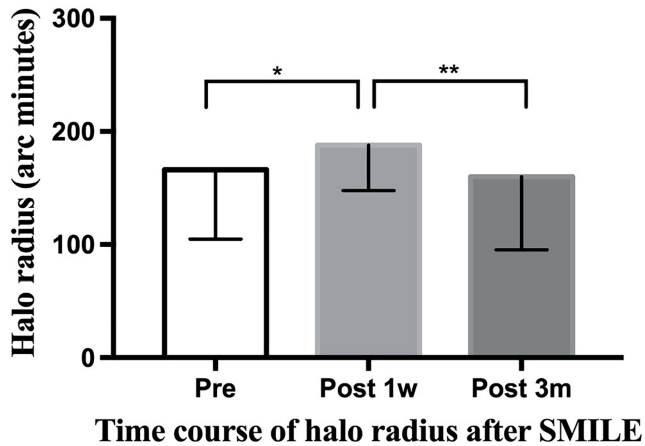

Fig. 2 Time course of halo radius after SMILE. **$P < 0.01$, *$P < 0.05$

Table 2 shows the correlation analysis between disk halo size and age, spherical equivalent refraction, and pupil parameters. Preoperative disk halo size was significantly correlated with SE (r = − 0.346, P = 0.020), minimum pupil size (r = 0.365, P = 0.014), and average pupil size (r = 0.310, P = 0.038). Disk halo size at postoperative 1 week was significantly correlated with age (r = 0.324, P = 0.030) and minimum pupil size (r = 0.297, P = 0.047). Disk halo size at postoperative 3 months was significantly correlated with lenticule diameter (r = − 0.362, P = 0.015), initial diameter (r = 0.311, P = 0.037), maximum pupil size (r = 0.312, P = 0.037), minimum pupil size (r = 0.440, P = 0.002), and average pupil size (r = 0.373, P = 0.012).

Discussion

Glare and halos remain an important factor in postoperative patient satisfaction [3–6]. This study was undertaken to investigate early changes in disk halo size produced by a glare source after SMILE.

We found that the disk halo size of patients undergoing SMILE initially increased, then decreased, eventually returning to the preoperative level at 3 months after surgery; this is consistent with results obtained by using other glare testing instruments. A study that used OQAS to observe changes in objective scatter index after SMILE found that, within 40 days after the surgery, the index was higher than preoperative levels, but recovered by 3 months after the surgery [14]. No significant difference was found in subjective intraocular forward scattering, assessed by using C-Quant before surgery, and at 1, 6, and 12 months after SMILE [15]. The results of our study are also consistent with subjective questionnaire studies on halos. In a study by Shah et al., no

Table 2 Correlation analysis between age, spherical equivalent refraction, pupil parameters, and halo radius (arc minutes)

Variables	Preoperation		Postoperative 1 week		*Postoperative 3 months*	
	R	*P*	*R*	*P*	*R*	*P*
Age (years)	− 0.098	0.520	0.324*	0.030	− 0.205	0.176
Preoperative SE (D)	− 0.346*	0.020	− 0.117	0.445	− 0.283	0.060
Lenticule thickness (um)	/	/	0.092	0.548	0.236	0.118
Lenticule diameter (mm)	/	/	− 0.242	0.109	− 0.362*	0.015
Dark pupil (mm)	0.106	0.487	0.037	0.809	0.281	0.062
Initial diameter (mm)	0.217	0.152	0.208	0.170	0.311*	0.037
Amplitude of contraction (mm)	− 0.086	0.576	− 0.012	0.937	− 0.057	0.712
Latency of contraction (ms)	− 0.095	0.535	− 0.005	0.975	0.041	0.790
Duration of contraction (ms)	0.019	0.904	− 0.009	0.955	− 0.106	0.487
Velocity of contraction (mm/s)	− 0.139	0.363	− 0.027	0.859	− 0.130	0.396
Latency of dilation (ms)	− 0.141	0.354	− 0.041	0.790	− 0.028	0.855
Duration of dilation (ms)	− 0.066	0.668	− 0.193	0.205	− 0.037	0.809
Velocity of dilation (mm/s)	0.192	0.207	0.024	0.875	0.149	0.328
Maximum pupil (mm)	0.227	0.133	0.150	0.325	0.312*	0.037
Minimum pupil (mm)	0.365*	0.014	0.297*	0.047	0.440*	0.002
Average pupil (mm)	0.310*	0.038	0.263	0.081	0.373*	0.012

SE spherical equivalent, *D* diopters, *R* correlation coefficient; *$P < 0.05$

deterioration in halos was reported by patients at postoperative 3 months, compared with preoperative levels of halos [19]. The time we observed for recovery from increased postoperative halos was similar to that in questionnaire studies after LASIK. At postoperative 3 months, halo scores were indistinguishable from baseline in a study by Schallhorn et al. [20] In addition, corneal transparency decreases for a short period of time after SMILE surgery and recovers at the later stage, which may explain the short-term increase observed in this study [21].

In this study, we found that the disk halo size in myopic patients before SMILE was correlated with SE, which is consistent with our previous studies [22]. Preoperative disk halo size was 166.22 ± 61.29 arcmin; this was notably different from 111.6 ± 39.8 arcmin in healthy eyes with limited refractive error [17], and was similar to other outcomes in myopic eyes [22]. Short-term disk halo size after SMILE is associated with age. This may explain lower comparative satisfaction with corneal refractive surgery in older patients [7].

At 3 months after surgery, the corneal condition in the patients became stable. Disk halo size was mainly related to dynamic pupil size, consistent with our previous study [22]. The disk halo size of the patients at 3 months postoperatively was also associated with the designed lenticule diameter. This is mainly because, compared with normal cornea, the edge of the lenticule may produce stray light that results in halos; thus, a larger lenticule diameter is more helpful in reducing postoperative halos.

Notably, the results of this study suggest no correlation between disk halo size after SMILE and dark pupil size. The relationship between dark pupil and vision quality after corneal refractive surgery has received much attention. Many studies have shown no relationship between the two [3–6, 23, 24], while others have shown that patients with larger dark pupils had worse postoperative visual quality [25, 26]. Our study supports the absence of a relationship and highlights the role of pupil size in dynamic pupillary light response in postoperative visual quality.

This study had certain limitations. First, because the refractive error was fully corrected with a lens before surgery, spherical aberration might have affected the evaluation of preoperative disk halo size. Second, the influence of substances, such as alcohol, on dynamic pupillary light response was not considered. Third, a long-term study of disk halo size after SMILE is necessary. It would be better to compare the outcomes with other optical quality measurements, such as OQAS and C-Quant.

In conclusion, disk halo size showed a temporary increase and returned to baseline after SMILE.

Authors' contribution Conception and design: Tian Han, Feng Zhao, Xun Chen, and Xingtao Zhou

Data collection: Tian Han, Feng Zhao, Xun Chen, Huamao Miao, and Zhuoyi Chen

Analysis and interpretation: Tian Han, Feng Zhao, Xun Chen, Huamao Miao, Zhuoyi Chen, and Xingtao Zhou

Obtained funding: Xingtao Zhou

Overall responsibility: Tian Han, Feng Zhao, Xun Chen, Huamao Miao, Zhuoyi Chen, and Xingtao Zhou

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Compliance with ethical standards

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

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