Effects of small incision lenticule extraction and femtosecond laser-assisted *in situ* keratomileusis on choroidal thickness and blood flow density in patients with myopia

SHIRUI YANG[1,2], TIANTIAN QIAN[3], MIN TANG[4], JING ZHANG[2], JIE HOU[2], YAHUI DONG[2] and YULIN LEI[2]

[1]Department of Ophthalmology, Binzhou Medical University, Binzhou, Shandong 256603, P.R. China; [2]Department of Ophthalmology, Jinan Mingshui Eye Hospital, Jinan, Shandong 250200, P.R. China; [3]Department of Internal Medicine, Jinan Zhangqiu District People's Hospital, Jinan, Shandong 250200, P.R. China; [4]Department of Ophthalmology, Heze Medical College, Heze, Shandong 274000, P.R. China

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Abstract. Corneal refractive surgery is often used to correct myopia, and after surgery attention is often focused on changes in vision and corneal response. However, studies on the posterior segment of the eye remain relatively scarce. The present study aimed to observe changes in choroidal thickness and blood flow density after small incision lenticule extraction (SMILE) and femtosecond laser-assisted *in situ* keratomileusis (FS-LASIK) using optical coherence tomography. Changes in spherical equivalent (SE), axial length (AL), choroidal thickness and choriocapillaris blood flow density were recorded before and after surgery in 35 patients (70 eyes) who underwent SMILE and 21 patients (42 eyes) who underwent FS-LASIK. Postoperative SE significantly improved in both groups ($P<0.05$), and AL was shorter than the baseline level ($P<0.05$). Choroidal thickness initially increased and subsequently decreased to preoperative levels at multiple measurement sites in both groups. No significant changes were observed in choriocapillaris blood flow density in the two groups postoperatively compared with preoperatively. In conclusion, the results indicated that SMILE and FS-LASIK exert minimal influence on the choroid. To the best of our knowledge, the current study presents one of the first comparative assessments of dynamic choroidal changes following SMILE and FS-LASIK, offering insights into structural alterations in the posterior segment post-surgery.

Correspondence to: Professor Yulin Lei, Department of Ophthalmology, Jinan Mingshui Eye Hospital, 5601 Longquan Road, Zhangqiu, Jinan, Shandong 250200, P.R. China
E-mail: leiyulin642@126.com

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Introduction

Myopia is a refractive error frequently attributed to elongation of the ocular axis (1). Severe myopia can lead to various complications, including myopic macular degeneration and amblyopia, resulting in vision impairment and marked health consequences, including retinal detachment and early-onset cataracts (2,3). In addition, myopia has been classified among the five serious ocular conditions that may lead to blindness (4). In recent years, the prevalence of myopia has increased rapidly, and the age of onset has gradually decreased to 15.6±4.2 years, making it a global health concern (5), with the global prevalence of myopia projected to reach 50% of the population by 2050 (4). The choroid plays a crucial role in the development of myopia (6). Myopic visual signals can lead to decreased choroidal blood flow, leading to a reduced supply of oxygen and nutrients to the sclera. These conditions result in reduced scleral strength and thickness, axial elongation and the focus of light rays in front of the retina, thereby causing myopia (7-9).

Following the application of orthokeratology lenses to treat myopia, the centre of the cornea flattens, the peripheral retinal refractive state shifts from relative hyperopic defocus to myopic defocus (10-12), the axial length (AL) of the eye shows decelerated growth and choroidal thickness (CT) markedly increases (13-15). Small incision lenticule extraction (SMILE) and femtosecond laser-assisted *in situ* keratomileusis (FS-LASIK) are currently the predominant corneal refractive surgical procedures. SMILE and FS-LASIK correct myopia by ablating the central stroma of the cornea, thereby reducing corneal curvature and enabling light to focus on the retina. Both these procedures yield comparable outcomes in terms of safety, efficacy, predictability and stability for correcting myopia and myopic astigmatism (16,17). Similarly, SMILE and FS-LASIK also reduces the central curvature of the cornea and alters the defocus state of the retina (18-20). Thus, whether the choroid undergoes the same changes after SMILE and FS-LASIK as observed after orthokeratology lens use remains unclear. To the best of our knowledge, studies on the choroid after corneal refractive surgery are relatively limited. Optical coherence tomography (OCT) represents a breakthrough in ophthalmic imaging, allowing for the scanning of multiple intraocular tissue structures and the evaluation of choroidal vasculature (21). The present study aimed to apply OCT to measure central and peripheral CT and blood flow density in patients with myopia before and after SMILE and FS-LASIK surgeries, to observe the choroidal changes induced by these two procedures.

Materials and methods

Patients. The present study enrolled patients who underwent SMILE or FS-LASIK surgery for myopia correction at Jinan Mingshui Eye Hospital (Jinan, China) between November 2020 and October 2022. All patients provided written informed consent for refractive surgery and the use of their data in research. The inclusion criteria were as follows: i) Age 18-30 years; ii) maximum annual increase in myopic spherical equivalent (SE) of -0.5 diopters (D) within 2 years; iii) SE ranging from -3.00 to -10.00 D; and iv) normal fundus oculi. Exclusion criteria included: i) Keratoconus or corneal ectasia; ii) corneal dystrophy; iii) scar constitution; iv) conjunctivitis; v) keratitis; vi) compromised immune function; and vii) mental instability. A total of 56 patients were included, with 35 patients in the SMILE group and 21 patients in the FS-LASIK group. The sex distribution and age range of the patients are presented in the results section. The study protocol adhered to the principles of The Declaration of Helsinki and received approval from the Human Ethics Committee of Jinan Mingshui Eye Hospital (approval no. 2020-020).

Ophthalmological examination. SE, AL, ablation depth (AD), CT and blood flow density were measured before surgery and at 1 week, 1 month and 3 months postoperatively. AL was obtained using the IOLMaster 500 (Zeiss AG; Oberkochen; Germany) to measure the distance from the anterior corneal surface to the retinal pigment epithelium.

CT was measured using 'Radial Dia 6.0 mm overlap radial scanning mode' of OCT for the macula (DRI-OCT Triton; Topcon Corporation). A circular area with a 6-mm diameter centred on the macular fovea was scanned. CT was defined as the vertical distance from Bruch's membrane to the choroid-sclera junction and was measured in micrometres. The scanning area was divided into the following regions for CT measurements: The centre of the macula (CT-C), 0.5 mm nasal (CT-N1), 1.5 mm nasal (CT-N2), 0.5 mm temporal (CT-T1), 1.5 mm temporal (CT-T2), 0.5 mm superior (CT-S1), 1.5 mm superior (CT-S2), 0.5 mm inferior (CT-I1) and 1.5 mm inferior (CT-I2) to the centre, as shown in Fig. 1.

To measure blood flow density, the 'OCT Angiography (OCTA) 4.5x4.5' scanning mode was selected (DRI-OCT Triton; Topcon Corporation). The macular centre was examined in a 4.5x4.5 mm area. Scattering of the retina generates artifacts anterior to the choroid, and the sensitivity of OCTA decreases sharply with increasing scanning depth, both of which affect the imaging quality of the blood flow (22,23). Therefore, to minimize measurement errors, the depth range of 10.4-31.2 μm below Bruch's membrane was selected to obtain the choriocapillaris blood flow density (CD) (22,24). The scanning area was divided into the following regions for CD measurements: Centre of the macula, 0.5 mm nasal, 0.5 mm temporal (CD-T), 0.5 mm superior and 0.5 mm inferior to the centre, as shown in Fig. 2.

All examinations were conducted between 8:00 and 11:00 a.m. to account for the circadian rhythm of the choroid (25). In addition, all procedures were performed by the same experienced optometrist to avoid systematic errors.

Surgical procedure. SMILE was performed using the VisuMax femtosecond laser (VisuMax-500; Zeiss AG) to create corneal lenticules and caps. The surgical plan was developed based on preoperative refractive diopter and entered into the device. Laser scanning was then initiated, followed by lenticule removal using forceps through the upper aperture.

FS-LASIK was performed as a two-step procedure. First, a corneal flap was created using the VisuMax femtosecond laser. Next, the patient was transferred to the excimer laser system (AMARIS-500E; SCHWIND eye-tech-solution GmbH), where the corneal flap was opened and the corneal stroma was ablated. Normal saline was used to irrigate the stromal bed and conjunctival sac, resulting in a smooth corneal flap. All surgeries were performed by the same qualified and experienced ophthalmologist.

Statistical analysis. SPSS 25.0 statistical software (IBM Corp.) was used for data analysis. Normally distributed data are presented as the mean ± standard deviation, while non-normally distributed data are presented as the median (25th percentile, 75th percentile). When comparing the baseline characteristics between the SMILE and FS-LASIK groups, independent sample Student's t-test was used for the analysis of normally distributed data, while the non-parametric Mann-Whitney U test was used for data not conforming to a normal distribution. When conducting overall intergroup and intragroup analyses of various parameters, a two-way mixed ANOVA was used for normally distributed data, while non-normally distributed data were analysed using the non-parametric K-related sample Friedman test for within-group comparisons and the Mann-Whitney U test for between-group comparisons, all followed by a Bonferroni post hoc test or correction as necessary. Correlations between datasets were performed using Spearman correlation analysis. $P<0.05$ was considered to indicate a statistically significant difference.

Results

Baseline characteristics. The present study included 56 patients (112 eyes; all surgeries were performed on both eyes). The patients had a mean age of 23.07±3.61 years and a mean SE of -5.75±1.77 D. The SMILE group had a mean age of 22.89±3.01 years and a mean SE of -5.76±1.67 D; this group included 35 patients (15 male patients and 20 female patients). The FS-LASIK group had a mean age of 23.38±4.51 years and a mean SE of -5.74±1.79 D; this group included 21 patients (7 male patients and 14 female patients). No significant differences were found between the groups in age, preoperative SE, AL, AD of the corneal stroma, CT or CD ($P>0.05$). Table I presents the baseline characteristic comparisons between the two groups.

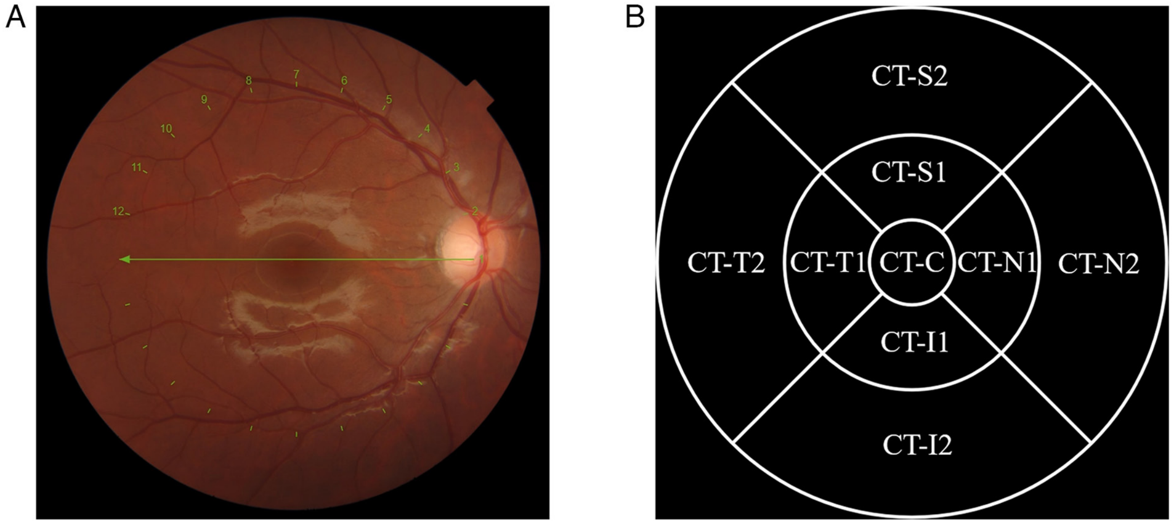

Figure 1. Measurement of CT. (A) Imaging of CT during optical coherence tomography scanning. (B) The scanned area was divided into different regions in the form of quadrants, including the following regions: CT-C, CT-N1, CT-N2, CT-T1, CT-T2, CT-S1, CT-S2, CT-I1 and CT-I2. Numbers 1 to 12 indicate the positions of the captured images. CT, choroidal thickness; CT-C, CT at the centre of the macula; CT-N1, CT at 0.5 mm nasal; CT-N2, CT at 1.5 mm nasal; CT-T1, CT at 0.5 mm temporal; CT-T2, CT at 1.5 mm temporal; CT-S1, CT at 0.5 mm superior; CT-S2, CT at 1.5 mm superior; CT-I1, CT at 0.5 mm inferior; CT-I2, CT at 1.5 mm inferior.

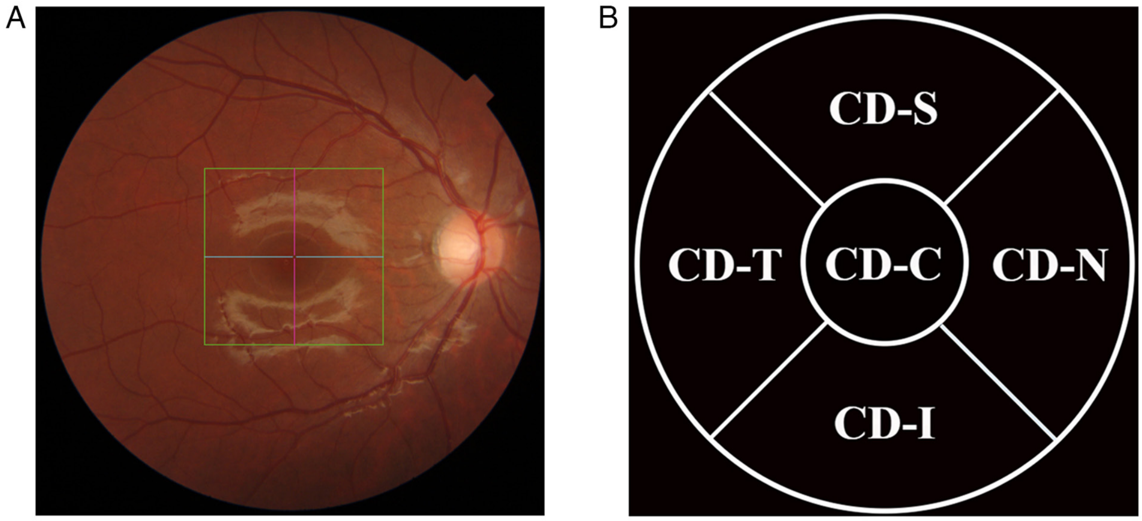

Figure 2. Measurement of CD. (A) Imaging of the choriocapillaris vessels during optical coherence tomography scanning. The square in the picture represents the scanning area used by the instrument to measure blood flow density, and the cross is the center of the scan. (B) The scanned area was divided into different regions in the form of quadrants, including the following regions: CD-C, CD-N, CD-T, CD-S and CD-I. CD, choriocapillaris blood flow density; CD-C, CD at the centre of the macula; CD-N, CD at 0.5 mm nasal; CD-T, CD at 0.5 mm temporal; CD-S, CD at 0.5 mm superior; CD-I, CD at 0.5 mm inferior.

Changes in SE and AL

Changes in SE. The SE at all postoperative time points was significantly increased compared with that before the surgery in each group (P<0.001). Statistically significant differences between the two groups were observed at 1 week and 1 month postoperatively (P<0.05) but not at the remaining time points (P>0.05) (Table II).

Changes in AL. The AL at each time point postoperatively was significantly shorter than preoperative AL in both groups (P<0.001). No significant differences were found between the two groups at each time point before and after surgery (P>0.05) (Table II).

Correlation between the shortening of AL and AD. A significant correlation was found between the shortening of AL and AD at 3 months postoperatively in the SMILE group compared with the preoperative values (P<0.001; Fig. 3A). In addition, a significant correlation was also found between the shortening of AL and AD at 3 months postoperatively in the FS-LASIK group (P=0.039; Fig. 3B).

Changes in CT

Changes in CT in the SMILE group. CT-C, CT-N1, CT-N2, CT-S1, CT-S2, CT-I1 and CT-I2 were significantly increased at 1 week postoperatively compared with their preoperative levels (P<0.001), followed by a decreasing trend and the return to preoperative thickness by 3 months after surgery (P>0.05). CT-T1 and CT-T2 remained significantly increased compared with preoperative values at all postoperative time points

Table I. Comparison of baseline characteristics between the SMILE and FS-LASIK groups.

Variable	SMILE	FS-LASIK	t/Z-value	P-value
Age, years	22.89±3.01	23.38±4.51	-0.447	0.658
SE, D	-5.76±1.67	-5.74±1.79	1.580	0.343
AL, mm	25.45 (24.70, 26.08)	25.62 (24.99, 26.34)	-0.884	0.377
AD, μm	98.37±25.27	92.74±22.35	1.192	0.236
CT-C, μm	227.69±82.07	211.83±63.11	1.323	0.189
CT-N1, μm	200.00 (151.25, 248.00)	177.00 (144.00, 226.75)	-1.328	0.184
CT-N2, μm	159.00 (123.00, 216.75)	141.50 (112.75, 202.00)	-1.614	0.107
CT-T1, μm	241.24±80.51	225.65±65.97	1.205	0.231
CT-T2, μm	252.27±76.23	230.42±63.50	1.678	0.096
CT-S1, μm	235.87±76.60	208.32±64.40	2.030	0.055
CT-S2, μm	245.74±71.49	216.88±58.12	2.202	0.060
CT-I1, μm	236.70±83.19	216.43±62.74	1.693	0.094
CT-I2, μm	234.50 (178.75, 297.75)	217.50 (170.50, 245.50)	-1.668	0.095
CD-C, %	55.52±4.91	55.23±4.66	0.534	0.595
CD-N, %	55.94±3.83	55.48±2.44	1.015	0.312
CD-T, %	57.22 (55.10, 58.90)	55.89 (53.72, 56.88)	-2.515	0.067
CD-S, %	51.01±3.91	50.90±3.35	0.398	0.691
CD-I, %	53.19 (51.06, 56.15)	53.74 (51.09, 55.60)	-0.237	0.621

Data are presented as the mean ± standard deviation or the median (25th percentile, 75th percentile). SMILE, small incision lenticule extraction; FS-LASIK, femtosecond laser-assisted *in situ* keratomileusis; SE, spherical equivalent; D, diopter; AL, axial length; AD, ablation depth; CT, choroidal thickness; CT-C, CT at the centre of the macula; CT-N1, CT at 0.5 mm nasal; CT-N2, CT at 1.5 mm nasal; CT-T1, CT at 0.5 mm temporal; CT-T2, CT at 1.5 mm temporal; CT-S1, CT at 0.5 mm superior; CT-S2, CT at 1.5 mm superior; CT-I1, CT at 0.5 mm inferior; CT-I2, CT at 1.5 mm inferior; CD, choriocapillaris blood flow density; CD-C, CD at the centre of the macula; CD-N, CD at 0.5 mm nasal; CD-T, CD at 0.5 mm temporal; CD-S, CD at 0.5 mm superior; CD-I, CD at 0.5 mm inferior.

Table II. Changes in SE and AL before and after the operation in the SMILE and FS-LASIK groups.

A, SE, D

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	-5.74±1.79	0.00±0.30	-0.03±0.27	0.01±0.31	612.340	<0.001
FS-LASIK	-5.76±1.67	0.33±0.28	0.29±0.28	-0.06±0.05	598.430	<0.001
P-value	0.343	<0.001	0.010	0.610		

B, AL, mm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	25.45 (24.70, 26.08)	25.29 (24.61, 25.94)	25.32 (24.59, 25.93)	25.29 (24.59, 25.93)	137.586	<0.001
FS-LASIK	25.62 (24.99, 26.34)	25.48 (24.88, 26.14)	25.48 (24.85, 26.14)	25.50 (24.85, 26.16)	84.274	<0.001
P-value	0.377	0.465	0.447	0.220		

Data are presented as the mean ± standard deviation or the median (25th percentile, 75th percentile). SMILE, small-incision lenticule extraction; FS-LASIK, femtosecond laser-assisted *in situ* keratomileusis; SE, spherical equivalent; D, diopter; AL, axial length.

(P<0.001); however, these two measurement indicators showed a slow growth trend at 1 month and 3 months postoperatively. Details on the levels of the CT parameters are presented in Table III and Fig. 4.

Changes in CT in the FS-LASIK group. CT-N1, CT-N2 and CT-I2 significantly increased at 1 week postoperatively compared with their preoperative levels (all P<0.05), followed by gradual decrease by 1 month. No significant difference was

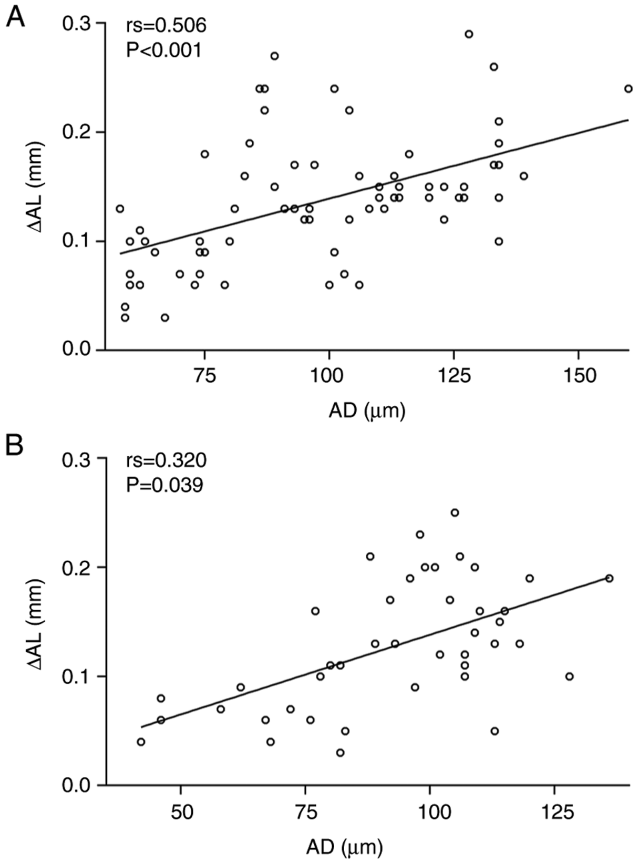

Figure 3. Scatter plot of the correlation between ΔAL and AD. (A) Scatter plot of the correlation between ΔAL and AD 3 months postoperatively in the small incision lenticule extraction group. (B) Scatter plot of the correlation between ΔAL and AD 3 months postoperatively in the femtosecond laser-assisted *in situ* keratomileusis group. ΔAL, amount of axial length shortening 3 months after surgery; AD, ablation depth.

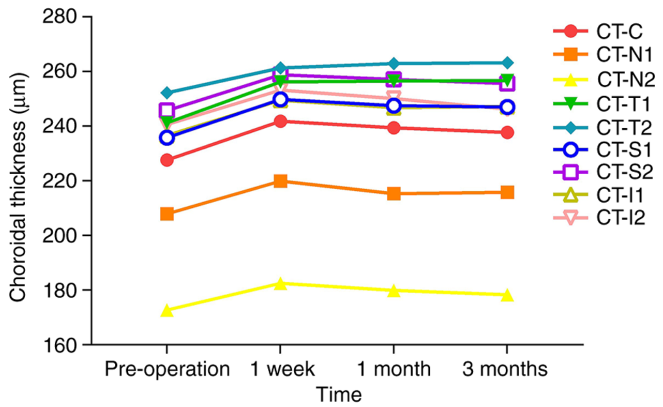

Figure 4. Change in the trend of CT before and after the operation in the small incision lenticule extraction group measured across different regions. Pre, pre-operation; CT, choroidal thickness; CT-C, CT at the centre of the macula; CT-N1, CT at 0.5 mm nasal; CT-N2, CT at 1.5 mm nasal; CT-T1, CT at 0.5 mm temporal; CT-T2, CT at 1.5 mm temporal; CT-S1, CT at 0.5 mm superior; CT-S2, CT at 1.5 mm superior; CT-I1, CT at 0.5 mm inferior; CT-I2, CT at 1.5 mm inferior.

found at 3 months postoperatively compared with the baseline (P>0.05). CT-T1 and CT-I1 showed no significant changes but followed a pattern of initial increase followed by reduction at 1 month postoperatively. All other measurement sites showed significantly greater thickness than their preoperative levels at all postoperative time points (P<0.05) but T2, S1 and S2 exhibited a slow increase, and CT-C exhibited a decrease at 3 months postoperatively. Details on the levels of the CT parameters are presented in Table III and Fig. 5.

Comparison of CT between the two groups. The CT-T2 in the SMILE group was significantly thicker than that in the FS-LASIK group at 1 month postoperatively (P=0.045). CT-S1 in the SMILE group was significantly thicker than that in the FS-LASIK group at 1 week (P=0.016), as was CT-S2 at both 1 week and 1 month postoperatively (P<0.05). No significant differences were observed between groups at other measurement sites across the postoperative timepoints (P>0.05) (Table III).

Changes in CD

Changes in CD in the SMILE group. A significant decrease in CD-T was observed at 1 week postoperatively (P=0.010), but the values returned to preoperative levels by 1 month. No significant changes were found at other observation sites (Table IV).

Changes in CD in the FS-LASIK group. No significant changes in CD parameters were observed among preoperative and postoperative groups (Table IV).

Comparison of CD between the two groups. No statistically significant differences were found between the surgical groups at any time point before or after surgery (Table IV).

Discussion

The choroid, an essential ocular tissue, responds to changes in internal visual signal transmission, and visual signals of peripheral myopic defocus on the retina induce choroidal thickening (26-28). Recent studies have shown that after correcting myopia with orthokeratology lenses, peripheral retinal myopic defocus results in increased CT (13-15). Although corneal refractive surgery also alters the retinal defocus state during myopia correction (19,20), the present study, in conjunction with existing research (29,30), revealed that choroidal responses may not entirely mirror those observed with orthokeratology.

In the present study, after SMILE and FS-LASIK, CT increased initially and then gradually returned to baseline at the majority of measurement sites. Among the two groups, only a very small number of measurement sites showed significant differences in choroidal thickness at very few time points. These findings are consistent with those of previous research. Xu *et al* (29) reported that CT increased after FS-LASIK but returned to baseline levels 3 months postoperatively. Zhang *et al* (30) observed a temporary increase in CT 2 h after FS-LASIK, which returned to preoperative levels at 1 week; however, the average thickness at 3 months postoperatively exceeded that at 2 h after the operation, which differs from the present study results. The authors attributed the transient increase to elevated intraocular pressure during surgery, which may stimulate the choroid, causing thickening. As intraocular pressure stabilizes, CT initially recovers, followed by an increase possibly related to myopic defocus of the peripheral retina, similar to orthokeratology mechanisms (30). Another

Table III. Changes in CT before and after the operation in the SMILE and FS-LASIK groups.

A, CT-C, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	227.69±82.07	241.83±84.35	239.46±83.41	237.77±81.29	14.024	<0.001
FS-LASIK	211.83±63.11	216.48±64.39	218.20±64.83	218.15±65.76	1.889	0.035
P-value	0.189	0.050	0.108	0.128		

B, CT-N1, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	200.00 (151.25, 248.00)	207.50 (155.00, 279.25)	205.00 (153.50, 265.00)	206.00 (152.50, 271.00)	31.108	<0.001
FS-LASIK	177.00 (144.00, 226.75)	187.50 (151.25, 228.75)	191.50 (144.25, 248.50)	192.00 (134.50, 239.75)	8.632	0.031
P-value	0.184	0.168	0.234	0.129		

C, CT-N2, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	159.00 (123.00, 216.75)	163.00 (12825, 230.25)	155.00 (122.00, 217.00)	154.00 (12.002, 220.25)	25.536	<0.001
FS-LASIK	141.50 (112.75, 202.00)	150.50 (115.75, 202.25)	145.00 (113.50, 193.00)	149.50 (105.00, 189.75)	10.832	0.013
P-value	0.107	0.188	0.220	0.222		

D, CT-T1, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	241.24±80.51	256.24±80.22	256.57±82.46	256.76±81.77	17.534	<0.001
FS-LASIK	225.65±65.97	234.62±70.26	233.00±69.26	230.70±70.09	2.581	0.057
P-value	0.231	0.103	0.085	0.060		

E, CT-T2, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	252.27±76.23	261.31±73.37	262.96±75.08	263.26±75.09	6.238	<0.001
FS-LASIK	230.42±63.50	237.25±66.84	237.50±67.50	237.68±65.17	3.113	0.039
P-value	0.096	0.063	0.045	0.058		

F, CT-S1, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	235.87±76.60	249.80±79.13	247.50±79.54	247.00±79.30	18.432	<0.001
FS-LASIK	208.32±64.40	216.58±62.16	219.52±61.59	219.68±61.93	3.097	0.030
P-value	0.055	0.016	0.061	0.056		

G, CT-S2, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value

Table III. Continued.

G, CT-S2, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	245.74±71.49	258.83±75.15	257.16±76.20	255.63±73.09	12.220	<0.001
FS-LASIK	216.88±58.12	223.22±62.13	225.58±64.18	226.83±61.10	3.683	0.030
P-value	0.060	0.010	0.022	0.064		

H, CT-I1, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	236.70±83.19	249.56±86.29	246.83±87.99	247.23±84.41	13.852	<0.001
FS-LASIK	216.43±62.74	223.30±65.26	222.45±64.91	221.47±68.42	1.966	0.140
P-value	0.094	0.058	0.077	0.060		

I, CT-I2, μm

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	234.50 (178.75, 297.75)	237.00 (201.25, 327.00)	229.50 (199.00, 304.25)	230.00 (193.25, 284.00)	27.965	<0.001
FS-LASIK	217.50 (170.50, 245.50)	225.00 (171.75, 257.00)	218.50 (170.50, 261.00)	222.00 (161.75, 271.50)	11.310	0.010
P-value	0.095	0.072	0.100	0.092		

Data are presented as the mean ± standard deviation or the median (25th percentile, 75th percentile). SMILE, small-incision lenticule extraction; FS-LASIK, femtosecond laser-assisted *in situ* keratomileusis; CT, choroidal thickness; CT-C, CT at the centre of the macula; CT-N1, CT at 0.5 mm nasal; CT-N2, CT at 1.5 mm nasal; CT-T1, CT at 0.5 mm temporal; CT-T2, CT at 1.5 mm temporal; CT-S1, CT at 0.5 mm superior; CT-S2, CT at 1.5 mm superior; CT-I1, CT at 0.5 mm inferior; CT-I2, CT at 1.5 mm inferior.

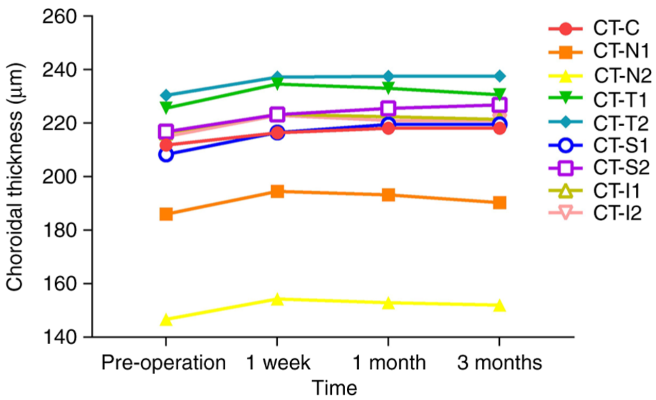

Figure 5. Change in the trend of CT before and after the operation in the femtosecond laser-assisted *in situ* keratomileusis group measured across different regions. Pre, pre-operation; CT, choroidal thickness; CT-C, CT at the centre of the macula; CT-N1, CT at 0.5 mm nasal; CT-N2, CT at 1.5 mm nasal; CT-T1, CT at 0.5 mm temporal; CT-T2, CT at 1.5 mm temporal; CT-S1, CT at 0.5 mm superior; CT-S2, CT at 1.5 mm superior; CT-I1, CT at 0.5 mm inferior; CT-I2, CT at 1.5 mm inferior.

study demonstrated that myopic defocus promotes the recovery of CT and slows axial elongation (31), further supporting the association between choroidal changes and retinal defocus state. In the present study, choroidal thickening occurred during the early postoperative period. In addition to the aforementioned mechanisms, we hypothesize that changes in signal molecule transmission along the retina-choroid pathway may contribute to these findings. Previous studies indicated that alterations in visual signals can regulate the release of dopamine in the dopamine pathway (32,33); an increase in dopamine secretion can lead to the thickening of the choroid and inhibit the progression of myopia, whereas a decrease in secretion has the opposite effect (7,34). Corneal refractive surgery reduces central corneal curvature, shifting the peripheral retina defocus from hyperopic to myopic (19,20); consequently, this emmetropization of the visual signal increases the secretion of dopamine from the retina to the choroid, increasing CT. This hypothesis aligns with the perspectives shared in the study by Cheng *et al* (35), where it was also considered that the release of dopamine is what caused the change in the thickness of the choroid. This mechanism may occur during the early postoperative period, as retinal areas adapt to the altered visual environment, after which dopamine secretion decreases (7) and CT gradually returns to baseline. In the present study, in both the SMILE and FS-LASIK groups, some measurement points, primarily at the macular centre (CT-C), temporal side (CT-T) or superior region (CT-S), remained increased compared with their preoperative levels throughout the study. These regions are known to have relatively greater

Table IV. Changes in CD before and after the operation in the SMILE and FS-LASIK groups.

A, CD-C, %

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	55.52±4.91	55.19±6.02	55.54±5.48	55.18±5.87	0.249	0.843
FS-LASIK	55.23±4.66	57.15±5.14	55.10±4.84	55.40±5.42	2.694	0.050
P-value	0.595	0.052	0.634	0.893		

B, CD-N, %

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	55.94±3.83	55.35±3.58	55.36±4.01	55.69±4.13	0.852	0.467
FS-LASIK	55.48±2.44	55.31±3.91	54.81±3.69	56.12±4.32	1.832	0.160
P-value	0.312	0.756	0.810	0.681		

C, CD-T, %

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	57.22 (55.10, 58.90)	56.43 (54.28, 57.86)	56.30 (54.36, 58.45)	56.97 (54.52, 59.06)	10.898	0.012
FS-LASIK	55.89 (53.72, 56.88)	55.25(53.73, 57.49)	56.10 (53.15, 57.80)	56.58 (53.69, 58.33)	0.756	0.521
P-value	0.067	0.261	0.140	0.489		

D, CD-S, %

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	51.01±3.91	51.58±3.86	51.94±3.84	52.06±4.74	2.029	0.111
FS-LASIK	50.90±3.35	52.08±3.50	51.86±3.53	50.89±4.07	2.492	0.085
P-value	0.691	0.794	0.730	0.189		

E, CD-I, %

Variable	Pre-operation	1 week	1 month	3 months	F/χ^2-value	P-value
SMILE	53.19 (51.06, 56.15)	53.83 (50.34, 56.46)	53.76 (51.66, 57.07)	54.45 (50.32, 57.56)	2.584	0.460
FS-LASIK	53.74 (51.09, 55.60)	54.02 (51.28, 56.01)	53.62 (50.62, 56.57)	53.74 (50.10, 58.13)	0.368	0.699
P-value	0.621	0.995	0.757	0.843		

Data are presented as the mean ± standard deviation or the median (25th percentile, 75th percentile). SMILE, small-incision lenticule extraction; FS-LASIK, femtosecond laser-assisted *in situ* keratomileusis; CD, choriocapillaris blood flow density; CD-C, CD at the centre of the macula; CD-N, CD at 0.5 mm nasal; CD-T, CD at 0.5 mm temporal; CD-S, CD at 0.5 mm superior; CD-I, CD at 0.5 mm inferior.

CT (36,37), and thicker choroid exhibits a delayed response to visual signalling (7). Although CT in these regions stayed above baseline, these variables demonstrated a slow increase or decline. However, the clinical relevance of CT changes remains unclear; the present study only tracked patients until 3 months post-surgery, and more long-term observations are required to clarify the outcomes.

Xu *et al* (29) reported a notable decrease in choroidal blood flow density 1 day after surgery, which returned to baseline near the macular centre by 1 month. Similarly, Chen *et al* (38) observed reduced vascular density in and around the optic disc 1 day after SMILE, with recovery by 1 week postoperatively. Another study revealed an initial decline in vascular density after FS-LASIK, followed by a gradual increase and return to preoperative levels within 1 month (39). In the present study, CD decreased at a single site in the SMILE group but returned to baseline. No significant changes were observed in other areas. These findings are consistent with those of Chen *et al* (40), who reported no significant changes in superficial or deep retinal vascular density post-surgery. In the present study, CD was specifically measured to minimize artifacts from the anterior retina and reduce potential errors from scanning deeper layers of the choroid (22-24). We hypothesize that postoperative changes in choroidal blood flow density may not be entirely absent but could occur in the deeper choroidal vasculature, which remains underexplored. Currently, although OCTA can be used to image the choriocapillaris blood flow, this technique has limitations (22,41), including reduced detection sensitivity in deeper tissues and artifacts during scanning, which limits the conclusions on the overall choroidal blood flow in the present study. Based on the results of the current study, it is proposed that temporary changes in intraocular pressure do not markedly affect choroidal blood flow. A previous study supports this view, showing that choroidal blood flow remains relatively stable during the early stages of intraocular pressure elevation after surgery (42). In the present study, although CT changed during the observation period, blood flow density remained largely stable, suggesting no strong association between the two parameters. Some studies have also found no clear association between CT and blood flow (29,43). Moreover, another study indicated that CT is more closely related to choroidal vascularity than to choriocapillaris perfusion (44). Given the structural complexity of the choroid, evaluating its vascular characteristics remains challenging, and further research is required to better understand choroidal vascular responses following corneal refractive surgery.

The present study also observed postoperative reductions in AL in both groups. AL elongation and choroidal thinning are known to correlate closely with myopia progression (45,46). Peripheral hyperopic defocus in myopia can further accelerate AL elongation (47), whereas correcting myopia can delay this progression (48). Chen *et al* (49) reported that in adolescents using orthokeratology lenses, AL growth slowed and CT increased markedly. Peripheral retinal myopic defocus induced by orthokeratology has been shown to substantially alter ocular development and slow myopia progression (10-12). In the current study, postoperative AL was significantly shorter than baseline, consistent with the effects observed with orthokeratology. The IOLMaster 500 (Zeiss AG) used for AL measurement in the present study calculates the distance from the anterior corneal surface to the retinal pigment epithelium (50); corneal refractive surgery reduces corneal thickness through stromal ablation, which may lead to shorter AL. The present data also indicated that AL shortening was correlated with stromal AD. However, Xu *et al* (29) reported no significant association between reduced AL and choroidal parameters. Therefore, it cannot be definitively concluded that AL reduction is related to increased CT or to changes in retinal myopic defocus.

The present study has several limitations, including a small sample size and a relatively short follow-up period, which limited the ability to assess long-term postoperative choroidal changes. Owing to limitations in imaging sensitivity, blood flow density in deeper choroidal layers was not assessed. Future studies should address these aspects for a more comprehensive understanding of the choroid.

In conclusion, an increase in CT following SMILE and FS-LASIK surgeries was observed in the present study. However, by the end of the observation period, CT at most locations had returned to preoperative levels, indicating that the change was not sustained. In addition, no significant changes in CD were observed. The present findings suggest that SMILE and FS-LASIK exert minimal influence on the choroid.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

The present study was conceived and designed by YL and SY. The experiments were performed by SY, MT and JZ. The data were analyzed by SY, TQ, JH and YD. YL contributed materials. SY, YL and TQ wrote the manuscript. All authors read and approved the final manuscript. JZ and YL confirm the authenticity of all the raw data.

Ethics approval and consent to participate

The study protocol adhered to the principles of The Declaration of Helsinki and received approval from the Human Ethics Committee of Jinan Mingshui Eye Hospital (approval no. 2020-020). All patients provided written informed consent.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Jonas JB, Panda-Jonas S, Dong L and Jonas RA: Clinical and anatomical features of myopia. Asia Pac J Ophthalmol (Phila) 13: 100114, 2024.
2. Du Y, Meng J, He W, Qi J, Lu Y and Zhu X: Complications of high myopia: An update from clinical manifestations to underlying mechanisms. Adv Ophthalmol Pract Res 4: 156-163, 2024.
3. Landreneau JR, Hesemann NP and Cardonell MA: Review on the myopia pandemic: Epidemiology, risk factors, and prevention. Mo Med 118:156-163, 2021.
4. Arnoldi K: Growing pains: The incidence and prevalence of myopia from 1950 to 2050. J Binocul Vis Ocul Motil 74: 118-121, 2024.
5. Liang J, Pu Y, Chen J, Liu M, Ouyang B, Jin Z, Ge W, Wu Z, Yang X, Qin C, *et al*: Global prevalence, trend and projection of myopia in children and adolescents from 1990 to 2050: A comprehensive systematic review and meta-analysis. Br J Ophthalmol 109: 362-371, 2025.
6. Liu Y, Wang L, Xu Y, Pang Z and Mu G: The influence of the choroid on the onset and development of myopia: From perspectives of choroidal thickness and blood flow. Acta Ophthalmol 99: 730-738, 2021.
7. Brown DM, Mazade R, Clarkson-Townsend D, Hogan K, Datta Roy PM and Pardue MT: Candidate pathways for retina to scleral signaling in refractive eye growth. Exp Eye Res 219: 109071, 2022.
8. Ostrin LA, Harb E, Nickla DL, Read SA, Alonso-Caneiro D, Schroedl F, Kaser-Eichberger A, Zhou X and Wildsoet CF: IMI-the dynamic choroid: New insights, challenges, and potential significance for human myopia. Invest Ophthalmol Vis Sci 64: 4, 2023.

9. Jonas JB, Jonas RA, Bikbov MM, Wang YX and Panda-Jonas S: Myopia: Histology, clinical features, and potential implications for the etiology of axial elongation. Prog Retin Eye Res 96: 101156, 2023.
10. Tang T, Lu Y, Li X, Zhao H, Wang K, Li Y and Zhao M: Comparison of the long-term effects of atropine in combination with orthokeratology and defocus incorporated multiple segment lenses for myopia control in Chinese children and adolescents. Eye (Lond) 38: 1660-1667, 2024.
11. Erdinest N, London N, Lavy I, Berkow D, Landau D, Morad Y and Levinger N: Peripheral defocus and myopia management: A mini-review. Korean J Ophthalmol 37: 70-81, 2023.
12. Vincent SJ, Cho P, Chan KY, Fadel D, Ghorbani-Mojarrad N, González-Méijome JM, Johnson L, Kang P, Michaud L, Simard P and Jones L: CLEAR-orthokeratology. Cont Lens Anterior Eye 44: 240-269, 2021.
13. Zhang R, Zhuang S, Zhou Y, Chin MP, Sun L, Jhanji V and Zhang M: Associations between choroidal thickness and rate of axial elongation in orthokeratology lens users. Photodiagnosis Photodyn Ther 51: 104450, 2025.
14. Liu M, Huang J, Xie Z, Wang Y, Wang P, Xia R, Liu X, Su B, Qu J, Zhou X, *et al*: Dynamic changes of choroidal vasculature and its association with myopia control efficacy in children during 1-year orthokeratology treatment. Cont Lens Anterior Eye 48: 102314, 2025.
15. Wang XQ, Chen M, Zeng LZ and Liu LQ: Investigation of retinal microvasculature and choriocapillaris in adolescent myopic patients with astigmatism undergoing orthokeratology. BMC Ophthalmol 22: 382, 2022.
16. Lin MY, Tan HY and Chang CK: Myopic regression after FS-LASIK and SMILE. Cornea 43: 1560-1566, 2024.
17. Ramirez-Miranda A, Mota ADL, Rosa GGDL, Serna-Ojeda JC, Valdez-García JE, Fábregas-Sánchez-Woodworth D, Navas A, Jiménez-Corona A and Graue-Hernandez EO: Visual and refractive outcomes after SMILE versus FS-LASIK: A paired-eye study. Cir Cir 92: 758-768, 2024.
18. Kim BK and Chung YT: Comparison of changes in corneal thickness and curvature after myopia correction between SMILE and FS-LASIK. J Refract Surg 39: 15-22, 2023.
19. Khanjian AT, Khodzhabekyan NV, Tarutta EP, Harutyunyan SG and Milash SV: Changes in the wavefront and peripheral defocus profile after excimer laser and orthokeratology corneal reshaping in myopia. Vestn Oftalmol 139: 87-92, 2023 (In Russian).
20. Du Y, Zhou Y, Ding M, Zhang M and Guo Y: Changes in relative peripheral refraction and optical quality in Chinese myopic patients after small incision lenticule extraction surgery. PLoS One 18: e0291681, 2023.
21. Zeppieri M, Marsili S, Enaholo ES, Shuaibu AO, Uwagboe N, Salati C, Spadea L and Musa M: Optical coherence tomography (OCT): A brief look at the uses and technological evolution of ophthalmology. Medicina (Kaunas) 59: 2114, 2023.
22. Tan B, Chua J, Wong D, Liu X, Ismail M and Schmetterer L: Techniques for imaging the choroid and choroidal blood flow in vivo. Exp Eye Res 247: 110045, 2024.
23. Spaide RF: Choriocapillaris flow features follow a power law distribution: Implications for characterization and mechanisms of disease progression. Am J Ophthalmol 170: 58-67, 2016.
24. Singh RB, Perepelkina T, Testi I, Young BK, Mirza T, Invernizzi A, Biswas J and Agarwal A: Imaging-based assessment of choriocapillaris: A comprehensive review. Semin Ophthalmol 38: 405-426, 2023.
25. Stone RA, Tobias JW, Wei W, Carlstedt X, Zhang L, Iuvone PM and Nickla DL: Diurnal gene expression patterns in retina and choroid distinguish myopia progression from myopia onset. PLoS One 19: e0307091, 2024.
26. She Z and Gawne TJ: The parameters governing the anti-myopia efficacy of chromatically simulated myopic defocus in tree shrews. Transl Vis Sci Technol 13: 6, 2024.
27. Ma JX, Tian SW and Liu QP: Effectiveness of peripheral defocus spectacle lenses in myopia control: A meta-analysis and systematic review. Int J Ophthalmol 15: 1699-1706, 2022.
28. Troilo D, Nickla DL and Wildsoet CF: Choroidal thickness changes during altered eye growth and refractive state in a primate. Invest Ophthalmol Vis Sci 41: 1249-1258, 2000.
29. Xu Z, Gui S, Huang J, Li Y, Lu F and Hu L: Effect of femtosecond laser in situ keratomileusis on the choriocapillaris perfusion and choroidal thickness in myopic patients. Curr Eye Res 46: 878-884, 2021.
30. Zhang J, He FL, Liu Y and Fan XQ: Comparison of choroidal thickness in high myopic eyes after FS-LASIK versus implantable collamer lens implantation with swept-source optical coherence tomography. Int J Ophthalmol 13: 773-781, 2020.
31. Zhu X: Temporal integration of visual signals in lens compensation (a review). Exp Eye Res 114: 69-76, 2013.
32. Zhang Y and Wildsoet CF: RPE and choroid mechanisms underlying ocular growth and myopia. Prog Mol Biol Transl Sci 134: 221-240, 2015.
33. Roy S and Field GD: Dopaminergic modulation of retinal processing from starlight to sunlight. J Pharmacol Sci 140: 86-93, 2019.
34. Zhou X, Pardue MT, Iuvone PM and Qu J: Dopamine signaling and myopia development: What are the key challenges. Prog Retin Eye Res 61: 60-71, 2017.
35. Cheng D, Qiao YL, Zhu XY, Ruan KM, Lian HL, Shen MX, Wang SL, Shen LJ and Ye YF: Change in choroid thickness and vascularity index associated with accommodation and aberration after small-incision lenticule extraction. Int J Ophthalmol 18: 672-682, 2025.
36. Gupta P, Jing T, Marziliano P, Cheung CY, Baskaran M, Lamoureux EL, Wong TY, Cheung CM and Cheng CY: Distribution and determinants of choroidal thickness and volume using automated segmentation software in a population-based study. Am J Ophthalmol 159: 293-301, 2015.
37. Mori Y, Miyake M, Hosoda Y, Uji A, Nakano E, Takahashi A, Muraoka Y, Miyata M, Tamura H, Ooto S, *et al*: Distribution of choroidal thickness and choroidal vessel dilation in healthy Japanese individuals: The Nagahama study. Ophthalmol Sci 1: 100033, 2021.
38. Chen Y, Liao H, Sun Y and Shen X: Short-term changes in the anterior segment and retina after small incision lenticule extraction. BMC Ophthalmol 20: 397, 2020.
39. Wang P, Hu X, Zhu C, Liu M, Yuan Y and Ke B: Transient alteration of retinal microvasculature after refractive surgery. Ophthalmic Res 64: 128-138, 2021.
40. Chen M, Dai J and Gong L: Changes in retinal vasculature and thickness after small incision lenticule extraction with optical coherence tomography angiography. J Ophthalmol 2019: 3693140, 2019.
41. Gandhi S, Pattathil N and Choudhry N: OCTA: Essential or gimmick? Ophthalmol Ther 13: 2293-2302, 2024.
42. Kiyota N, Shiga Y, Ichinohasama K, Yasuda M, Aizawa N, Omodaka K, Honda N, Kunikata H and Nakazawa T: The impact of intraocular pressure elevation on optic nerve head and choroidal blood flow. Invest Ophthalmol Vis Sci 59: 3488-3496, 2018.
43. Sogawa K, Nagaoka T, Takahashi A, Tanano I, Tani T, Ishibazawa A and Yoshida A: Relationship between choroidal thickness and choroidal circulation in healthy young subjects. Am J Ophthalmol 153: 1129-1132.e1, 2012.
44. Wang Y, Liu M, Xie Z, Wang P, Li X, Yao X, Tian J, Han Y, Chen X, Xu Z, *et al*: Choroidal circulation in 8- to 30-year-old chinese, measured by SS-OCT/OCTA: Relations to age, axial length, and choroidal thickness. Invest Ophthalmol Vis Sci 64: 7, 2023.
45. Tian F, Zheng D, Zhang J, Liu L, Duan J, Guo Y, Wang Y, Wang S, Sang Y, Zhang X, *et al*: Choroidal and retinal thickness and axial eye elongation in Chinese junior students. Invest Ophthalmol Vis Sci 62: 26, 2021.
46. Xie J, Ye L, Chen Q, Shi Y, Hu G, Yin Y, Zou H, Zhu J, Fan Y, He J and Xu X: Choroidal thickness and its association with age, axial length, and refractive error in Chinese adults. Invest Ophthalmol Vis Sci 63: 34, 2022.
47. Chakraborty R, Read SA and Collins MJ: Hyperopic defocus and diurnal changes in human choroid and axial length. Optom Vis Sci 90: 1187-1198, 2013.
48. Read SA, Collins MJ and Sander BP: Human optical axial length and defocus. Invest Ophthalmol Vis Sci 51: 6262-6269, 2010.
49. Chen Z, Xue F, Zhou J, Qu X and Zhou X: Effects of orthokeratology on choroidal thickness and axial length. Optom Vis Sci 93: 1064-1071, 2016.
50. Shi Q, Wang GY, Cheng YH and Pei C: Comparison of IOL-Master 700 and IOL-Master 500 biometers in ocular biological parameters of adolescents. Int J Ophthalmol 14: 1013-1017, 2021.