• Clinical Research •

Changes in the peripapillary vasculature and macular thickness after cataract surgery using two phacoemulsification systems with optical coherence tomography angiography

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Abstract

● **AIM:** To assess the changes in the peripapillary vasculature and macular thickness after cataract surgery using two phacoemulsification systems with optical coherence tomography angiography (OCTA).

● **METHODS:** Fifty-two eyes of 52 patients with age-related cataract were randomized into two groups for phacoemulsification: Infiniti group (26 patients) using the Infiniti phacoemulsification system with gravity-fluidics and Centurion group (26 patients) using the Centurion phacoemulsification system with active-fluidics. The peripapillary vessel density (PVD) and macular thickness were examined using OCTA at baseline and at 1d, 1 and 3mo after cataract surgery.

● **RESULTS:** In the Infiniti group, the PVD was significantly reduced at 1d after the cataract surgery ($P<0.001$). However, the retinal nerve fiber layer (RNFL) thickness showed no significant change during the follow-up. Change in PVD 1d postoperatively was significantly negatively correlated to the cumulative dissipated energy (CDE), estimated fluid usage (EFU), effective phacoemulsification time (EPT), intraocular pressure (IOP), and total operating time (TOT; $P<0.05$). The macular thickness was significantly increased in all regions after the cataract surgery ($P<0.05$). However, no significant changes were found in the macular vessel density (VD) during the follow-up ($P>0.05$). In the Centurion group, the VD and thickness in the optic papilla and macula did not significantly change in all regions during the follow-up (all $P>0.05$). The best-corrected visual acuity (BCVA) significantly improved in both groups postoperatively ($P<0.001$).

● **CONCLUSION:** Using the Infiniti phacoemulsification system, OCTA provides a promising analysis of retinal vascular alterations, demonstrating a reduction of the PVD and an increase in the macular thickness. The Centurion phacoemulsification system can provide better retinal vasculature preservation during cataract surgery.

● **KEYWORDS:** cataract surgery; phacoemulsification system; retinal vasculature; optical coherence tomography angiography

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INTRODUCTION

Phacoemulsification is one of most common ophthalmic surgical procedures, usually resulting in a significant improvement in vision quality for elderly cataract patients[1]. Maintaining anterior chamber stability is a key factor to ensure the success of cataract surgery[2]. Large fluctuations in intraocular pressure (IOP) during cataract surgery increase the risk for surgical complications[3]. Before the Centurion Vision System (Alcon Laboratories, Inc., Fort Worth, TX, USA) became commercial available, previous platforms were almost gravity-based phacoemulsification aspiration devices. An air pump or pressurized irrigation bottle with gas has been used to keep the IOP stable in the previous platforms. However, since the gas infusion pressure does not necessarily vary with response to the changing aspiration flow rate, the effect is the same as raising the bottle height[4]. As an active-fluidics torsional phacoemulsification machine, the Centurion Vision System can maintain a preset IOP by using a compliant irrigation bag, which is squeezed in response to the aspiration flow rate and estimated incision leakage[4]. This is considered especially beneficial in preventing a post-occlusion surge, which could potentially collapse the operating chamber.

Changes in macular vascular density (VD) and blood flow areas after gravity-based phacoemulsification may affect the recovery of visualacuity[5]. Emeriewen *et al*[6] reported that patients experienced a decrease in visual acuity at different time-points caused by ischemic optic neuropathy, using a gravity-based phacoemulsification system. Li *et al*[7] also indicated that there was a significant reduction in the superficial retinal VD in patients with myopia after cataract surgery. However, the effects of phacoemulsification on the macular microvascular changes using an active-fluidics phacoemulsification system remain controversial[8]. Therefore, the effects on the retinal vascular system and the vision are still not clear.

Optical coherence tomography angiography (OCTA) is the latest microvascular imaging method that is used widely in retinal microvascular imaging[9]. It works by tracking the motion of erythrocytes and comparing continuous b-scan signals from the same location. In addition, the technique also provides additional information on the retinal and choroidal capillary networks[9-10]. Therefore, OCTA has been used for the quantitative and qualitative investigation of the ocular vasculature[11]. This study aimed to assess the retinal vasculature and thickness using OCTA with two phacoemulsification platforms: the Centurion Vision System with active-fluidics and the Infiniti Vision System (Alcon Laboratories, Inc., Fort Worth, TX, USA) with gravity-fluidics configuration.

SUBJECTS AND METHODS

Ethical Approval The Ethics Committee of the Tianjin Medical University approved the study (2020KY-15), which is in accordance with the Declaration of Helsinki.

Study Design This prospective randomized study was conducted at Tianjin Medical University Eye Hospital, Tianjin, China, from August 2018 to July 2020. All the consecutive cases of cataract surgery were performed by one surgeon. An independent observer randomly assigned participants into two groups using an envelope technique: the Infiniti group and the Centurion group.

Patients who underwent monocular phacoemulsification for uncomplicated cataract with intraocular lens (IOL) implantation were enrolled. All the patients were over 40 years old and had no other systemic pathologies that would interfere with the ocular or systemic circulation. The nuclear sclerosis grade was determined using a slit-lamp biomicroscope according to the Lens Opacities Classification System II (LOCS II). All the patients had mild and moderate cataract (nuclear sclerosis grades 1 and 2). The exclusion criteria were obvious postoperative corneal oedema which prevented high-quality imaging and ocular hypertension; inflammatory cells >5 in the anterior chamber postoperation; a history of previous ocular surgery; evidence of retinal pathologies such as retinal vascular diseases and complications such as posterior capsular rupture during operation. To ensure the accuracy of the measurement, all the scans with layer segmentation error, signal strength index <50, or significant motion artefacts in images were excluded.

Data Collection Each participant underwent a comprehensive preoperative ophthalmic examination. The assessed metrics included the best-corrected visual acuity (BCVA); the IOP, as measured by Goldmann applanation tonometry; a slit-lamp examination; and fundoscopy. The axial length was measured using the IOL Master system (Carl Zeiss, Meditec, Germany). The corneal topography was determined using a Scheimpflug device (Pentacam, Oculus Optikgerate GmbH). The endothelial cell count was measured using a specular microscope (SP-1P, Topcon Europe Medical B.V., Netherlands). A b-scan ultrasound recording was documented (AVISO, Quantel Medical, Clermont-Ferrand, France). Clinical history was also taken from participants, including demographic characteristics and the presence of hypertension, diabetes, hyperlipidemia and other systemic conditions. Systolicblood pressure (SBP) and diastolic blood pressure (DBP) were measured using a digital automatic BP monitor. Mean arterial pressure (MAP) was calculated using the expression MAP=DBP+1/3 (SBP-DBP), and mean ocular perfusion pressure (MOPP) was calculated using the equation MOPP=2/3 (MAP-IOP) at the time of OCTA. All the procedures were performed and the analyses conducted by an optometrist or technician, respectively.

OCTA Image Acquisition and Processing An OCTA image was obtained using RTVue XR OCT (Optovue, Inc., Fremont, CA, USA; Software V.2017.1.0.155). A split-spectrum amplitude decorrelation algorithm was used to extract the OCTA images, which operated an A-scan of 70 000 Hz scans per second. During image processing, the Motion Correction Technology function was used to correct the horizontal and vertical scans for eye movement[12].

The optic disc area was measured using a 4.5×4.5-mm^2 OCTA scan. The peripapillary vessel density (PVD) was automatically captured from the optic disc segment that extended in a 0.75-mm-wide elliptical annulus from the optic disc boundary[13]. The retinal nerve fiber layer (RNFL) thickness measurements were obtained using a 3.45 mm radius ring centered on the optic disc (Figure 1). The macular area was covered using a 3.0×3.0-mm^2 OCTA scan. The superficial

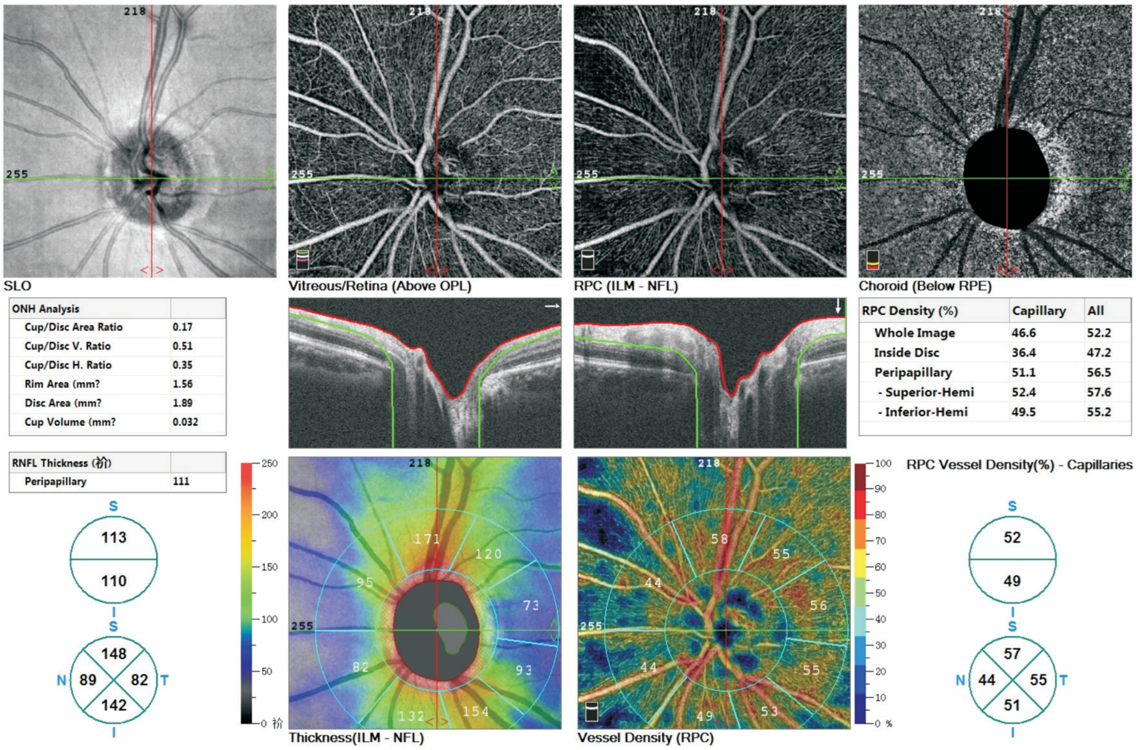

Figure 1 A 4.5×4.5-mm^2 image of optic disc angiogram.

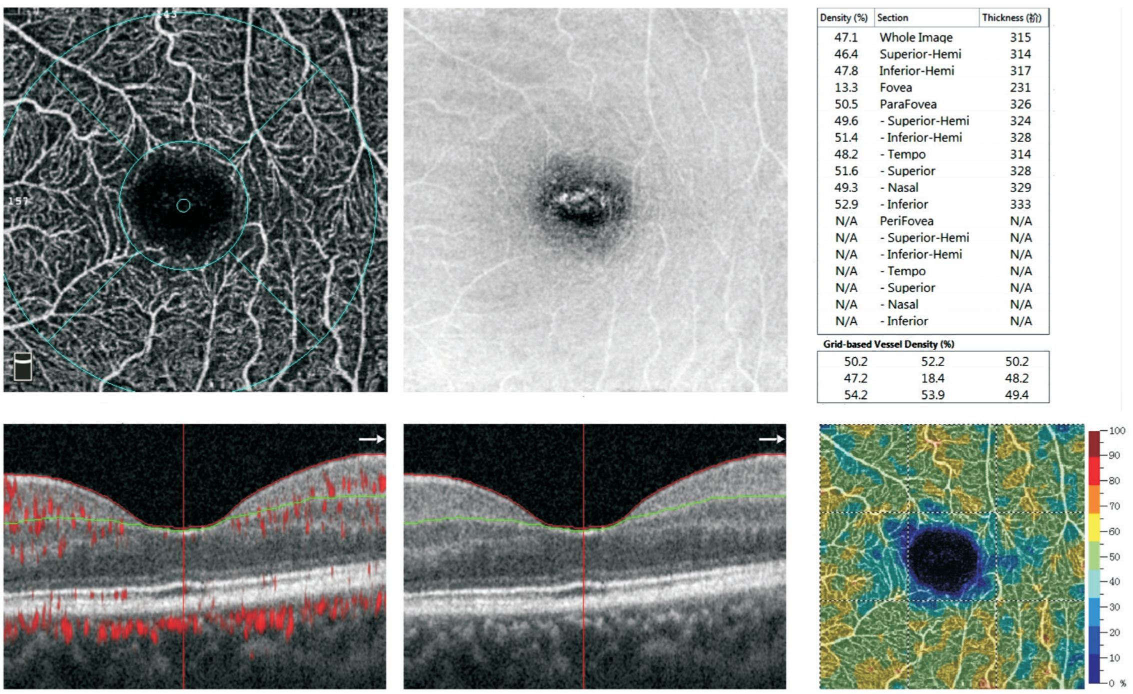

Figure 2 A 3×3-mm^2 image of superficial capillary plexus angiogram.

capillary plexus (SCP) was automatically selected from the area 3 μm below the inner limiting membrane (ILM) to 15 μm below the inner plexiform layer (IPL; Figure 2); the deep capillary plexus (DCP) was automatically selected from the area 15 to 70 μm below the IPL[14]. The macular thickness was measured from the ILM to the middle of the retinal pigment epithelium Bruch's membrane complex. The measurement area of the fovea was 1 mm diameter in the center of macula, and that of the parafovea was a 2 mm ring zone that surrounded the fovea.

Cataract Surgical Procedures Phacoemulsification was completed using the Infiniti Vision System or the Centurion Vision System. Briefly, after topical anesthesia was administered, a 2.2 mm clear corneal self-sealing incision, continuous capsulorhexis, hydrodissection, phacoemulsification, and irrigation/aspiration of the residual lens cortex were performed sequentially. A hydrophobic acrylic IOL (Alcon Laboratories, Inc., Fort Worth, TX, USA) was used in the capsular bag. The patients in both groups received levofloxacin (Cravit) and prednisolone acetate 1% (Pred Forte) eyedrops four times a day for 1-week after the surgery, followed by tapering for 3wk.

Statistical Analysis The normality of the data distribution was tested using the Kolmogorov-Smirnov test. After confirmation of the normality assumption, the data were generally presented as mean±standard deviation (SD) values. The comparisons of the baseline were performed using the *t*-test. The preoperative and postoperative measurements were compared using repeated measures with analysis of variance tests with Bonferroni corrections. The Pearson correlation analyses were performed to determine the relationships between the changes in the PVD at each timepoint postoperatively and the related clinical factors. Statistical analyses were performed using SPSS version 22.0 (SPSS, Inc., Chicago, IL, USA). Probability values of $P<0.05$ were considered significant.

RESULTS

A total of 52 eyes of 52 individuals were included in this study: 26 patients in the Infiniti group and 26 patients in the Centurion group. The general patient characteristics are presented on Table 1.

Table 1 Patient demographic and clinical characteristics

Parameters	Infiniti group (*n*=26)	Centurion group (*n*=26)	*P*
Sex, male/female (*n*)	11/15	14/12	0.261
Age (y)	63.62±5.53	65.50±6.85	0.280
SE (D)	-0.14±0.56	-0.22±0.68	0.637
CCT (μm)	541.81±20.23	537.38±20.63	0.330
ACD (mm)	3.72±0.16	3.70±0.14	0.528
AL (mm)	23.46±0.78	23.43±0.66	0.875
SBP (mm Hg)	119.31±5.18	118.23±8.32	0.578
DBP (mm Hg)	75.73±7.24	74.19±7.96	0.469
MAP (mm Hg)	90.21±6.30	88.87±6.58	0.459
MOPP (mm Hg)	49.94±5.34	49.75±4.31	0.893
Pulse (bpm)	78.15±6.51	76.65±8.61	0.482
Glucose (mmol/L)	5.32±0.44	5.35±0.48	0.795
HbA1c (%)	5.06±0.53	5.09±0.59	0.882
Cholesterol (mmol/L)	4.43±1.06	4.48±0.89	0.853
Triglycerides (mmol/L)	1.32±0.23	1.47±0.59	0.242

SE: Spherical equivalent; CCT: Central corneal thickness; ACD: Anterior chamber depth; AL: Axial length; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; MOPP: Mean ocular perfusion pressure; bpm: Beat per minute; MAP=DBP+1/3 (SBP-DBP); MOPP=2/3 (MAP-IOP).

The Infiniti group showed a longer surgical time and irrigation/aspiration time (I/A T) than the Centurion group (Infiniti: 373.89±66.38s *vs* Centurion: 337.35±40.10s; $P=0.021$; Infiniti: 104.08±15.96s *vs* Centurion: 90.92±8.28.10s; $P<0.001$). In addition, the estimated fluid usage (EFU) of the Infiniti group was greater than that of the Centurion group with no significant (Infiniti: 78.46±15.15 mL *vs* Centurion: 71.92±10.96 mL, $P=0.081$). There was no difference in either the effective phacoemulsification time (EPT) or cumulative dissipated energy (CDE) in both groups (EPT: $P=0.316$; CDE: $P=0.111$).

The BCVA was significantly better in each group at all time-points after surgery ($P<0.001$). The IOP increased significantly at 1d postoperatively in the Infiniti group ($P<0.001$) but not significantly different between baseline and 1mo postoperatively. The IOP measurementswere similar in the Centurion group during the follow-up ($P=0.117$).

In the Infiniti group, the PVD showed a significant decrease at 1d after the surgery ($P<0.001$). The PVDs were not significantly changed from 1mo after the surgery compared to the baseline values. Moreover, there were no significant changes in the macular VD measurements during the follow-up ($P>0.05$). In the Centurion group, there were no significant changes in the macular VD and PVD at any time-point after the surgery ($P>0.05$; Tables 2 and 3).

In the Infiniti group, the macular thickness showed a significant increase in all regions during the follow-up ($P<0.05$). However, there were no significant changes in the macular thickness in the Centurion group at any time-point after the surgery ($P>0.05$). Moreover, no significant changes were observed in the RNFL thickness in both groups during the follow-up ($P>0.05$; Table 4).

The Pearson correlation analyses revealed that the IOP, EPT, EFU, CDE, and total operating time (TOT) values were correlated significantly with the change in the PVD at 1d after the surgery in the Infiniti group ($P<0.001$; Figure 3). However, no significant correlations were found for age, MOPP and I/A T ($P>0.05$; Table 5).

DISCUSSION

In this study, the PVD decreased significantly at 1d postoperatively in the Infiniti group, even when the RNFL thickness did not change significantly during the follow-up. However, OCTA detected no significant changes in PVD and RNFL thickness in the Centurion group after the cataract surgery.

The reason for the changes in PVD was not completely clear. The peripapillary capillaries constitute a superficial layer of capillaries with a relatively constant caliber, and these run parallel to the RNFL in the peripapillary region[15]. Considering the unique pattern and distribution of the vessels, the PVD was considered particularly vulnerable to the elevated IOP when compared with other retinal capillaries[16].

Previous studies on the gravity-fluidics configuration have revealed that the IOP varies with the aspiration flow rate; increasing or decreasing the aspiration flow rate results in lower or higher IOP[17-18]. Perfusion pressure is an important determinant of ocular blood flow, which is equal to the mean blood pressure minus IOP[19]. A decrease in perfusion

Table 2 OCTA parameters in the Infiniti group

Parameters	Baseline	1d	1mo	3mo	*P*
SCP (%)					
Whole image	43.25±4.38	42.81±4.26	41.85±4.16	41.19±3.93	0.283
Parafovea	47.54±5.33	47.26±5.15	46.25±4.26	46.08±4.46	0.625
Fovea	17.37±2.79	17.50±2.62	16.86±2.82	16.45±2.53	0.476
DCP (%)					
Whole image	47.40±4.16	45.49±3.65	46.65±4.05	46.85±3.94	0.364
Parafovea	49.74±5.54	47.55±5.42	48.59±5.46	49.47±5.23	0.462
Fovea	26.93±6.29	25.25±6.05	25.79±6.22	26.74±6.07	0.731
RPC (%)					
Whole image	49.30±2.83	46.80±2.49	48.21±2.59	48.50±2.20	<0.001
Peripapillary	53.67±3.43	51.13±2.86	52.83±3.19	52.64±2.73	<0.001

SCP: Superficial capillary plexus; DCP: Deep capillary plexus; RPC: Radial peripapillary capillary.

Table 3 OCTA parameters in the Centurion group

Parameters	Baseline	1d	1mo	3mo	*P*
SCP (%)					
Whole image	44.54±2.39	44.84±2.35	44.13±2.34	44.99±2.26	0.546
Parafovea	46.66±2.74	47.02±3.06	46..33±2.80	46.66±2.85	0.861
Fovea	18.39±4.36	19.05±4.06	18.35±3.96	19.02±4.22	0.880
DCP (%)					
Whole image	47.71±4.46	47.24±4.51	48.30±4.34	47.50±4.45	0.844
Parafovea	50.47±4.91	49.25±5.10	50.88±5.09	51.06±4.91	0.562
Fovea	30.99±7.01	29.65±6.60	31.25±6.82	32.05±5.96	0.622
RPC (%)					
Whole image	48.40±2.26	48.99±2.66	49.53±1.99	49.56±3.37	0.339
Peripapillary	52.89±2.89	53.25±2.76	53.32±2.19	53.40±3.50	0.925

SCP: Superficial capillary plexus; DCP: Deep capillary plexus; RPC: Radial peripapillary capillary.

Table 4 Measured macular thickness and RNFL thickness

Groups	Parameters	Baseline	1d	1mo	3mo	*P*
Infiniti group	Macular thickness (μm)					
	Whole image	301.42±7.69	308.31±7.18	307.46±7.61	305.69±7.57	0.007
	Parafovea	312.00±8.57	319.15±7.68	318.54±8.33	316.23±10.50	0.018
	Fovea	242.23±9.66	249.69±8.39	251.54±8.73	248.58±11.58	0.005
	RNFL (μm)	108.65±12.90	116.27±11.40	114.15±12.00	113.81±10.40	0.122
Centurion group	Macular thickness (μm)					
	Whole image	305.12±8.71	303.65±6.99	306.12±7.92	306.39±6.91	0.173
	Parafovea	315.04±11.82	312.46±11.67	317.19±14.25.	318.38±11.37	0.329
	Fovea	248.96±13.73	245.45±11.11	252.19±14.25	253.39±11.38	0.113
	RNFL (μm)	110.81±10.77	117.42±12.08	114.46±12.23	115.19±11.82	0.240

RNFL: Retinal nerve fiber layer.

pressure may significantly decrease the ocular blood flow in the absence of vascular autoregulation[19-20]. Therefore, the fluctuations in the IOP may cause an impairment of the optic nerve perfusion, as well as retina[21-22]. In our study, the IOP increased significantly at 1d postoperatively in the Infiniti group and had a significant negative correlation with the change in PVD. We speculated that the larger IOP fluctuations with the gravity-fluidics configuration may have given rise to an injury to the retina, leading to PVD reduction after the surgery. A number of studies have shown that a reduced optic nerve head perfusion plays a crucial role in the pathogenesis of glaucoma[23-24]. Although the BCVA improved significantly in both groups postoperatively, the long-term implications from the changes in the PVD are unknown at present, especially in retinal vascular diseases. Meanwhile, there were no statistically significant changes in the PVD compared to baseline from 1mo postoperatively. This may have been due to the autoregulatory capacity of the retinal blood vessels[16]. Autoregulation serves to maintain a relatively constant blood flow in the wake of the perfusion pressure fluctuations. Previous studies have documented changes in retinal vascular endothelial cells, smooth muscle cells, and pericytes as part of the aging process[25]. However, the rate of this decline displays a wide inter-individual variability[16].

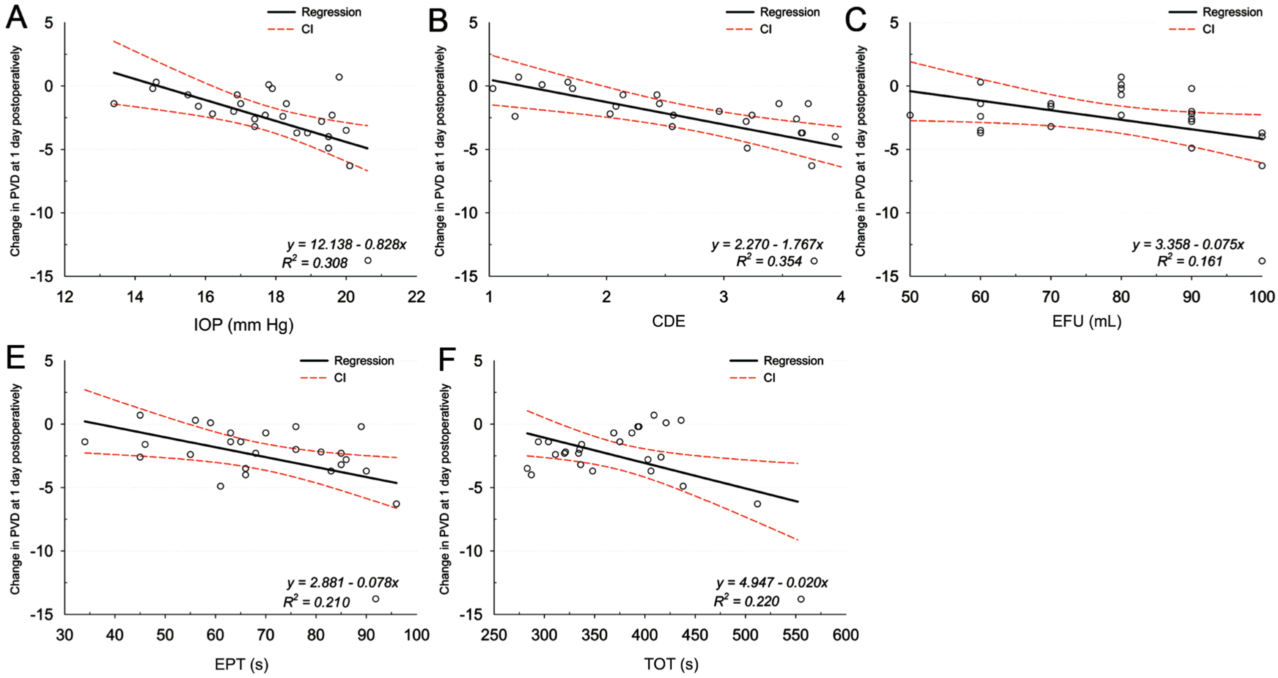

Figure 3 The IOP, EPT, EFU, CDE and TOT are negatively correlated with the change in PVD at 1d postoperatively IOP: Intraocular pressure; EPT: Effective phacoemulsification time; EFU: Estimated fluid usage; CDE: Cumulative dissipated energy; TOT: Total operating time; PVD: Peripapillary vessel density.

Table 5 Correlation between the changes in the PVD postoperatively and variations in the Inifiniti group

Factors	1d		1mo		3mo	
	r	*P*	*r*	*P*	*r*	*P*
Age (y)	0.275	0.173	0.074	0.718	0.013	0.950
IOP (mm Hg)	0.555	0.003	0.031	0.880	0.043	0.834
MOPP (mm Hg)	0.319	0.113	0.057	0.783	0.200	0.326
EPT (s)	0.458	0.019	0.129	0.530	0.026	0.900
I/A T (s)	0.303	0.133	0.076	0.710	0.272	0.178
EFU (mL)	0.402	0.042	0.061	0.767	0.231	0.257
CDE (%)	0.595	0.001	0.310	0.123	0.193	0.344
TOT (s)	0.469	0.016	0.030	0.884	0.322	0.109

CDE: Cumulative dissipated energy; EFU: Estimated fluid usage; EPT: Effective phacoemulsification time; MOPP: Mean ocular perfusion pressure; I/A T: Irrigation/aspiration time; IOP: Intraocular pressure; PVD: Peripapillary vessel density; TOT: Total operating time.

Another reason for the changes in the PVD may have been that the active-fluidics configuration achieved greater surgical efficiency than the gravity-fluidics configuration[17]. In this study, we observed significantly less I/A T, EFU and TOT with the active-fluidics configuration than with the gravity-fluidics configuration. Moreover, there were significant negative correlations between the change in the PVD at 1d after the surgery and the EPT, EFU, CDE and TOT values in the Infiniti group. During cataract surgery, the barrier between the anterior and posterior segment is affected by IOP fluctuations and immense fluid perfusion. This can cause cortical debris to leak into the vitreous even in the absence of capsular damage. The mechanical forces can arouse ocular globe deformation, which may lead to vitreous destabilization and inflammatory reactions in the vitreoretinal tissues[26]. Previous studies have shown that the Centurion phacoemulsification system required less energy to remove a cataractous lens in comparison to the Infiniti phacoemulsification system[4], which may have induced less inflammatory reaction in the anterior segment of the eye. Although there was no difference in either the EPT or CDE values in both groups, the longer surgical time compared to the Centurion group, may have led to more severe inflammation after the surgery in the Infiniti group. The changes in the inflammatory levels may have resulted in the reduction of the PVD in the Infiniti group at 1d postoperatively.

Previous researches have indicated that the abnormal VDs in the SCP and DCP are closely related to the decline of visual function[27]. Although there was no significant change in the macular VD in both groups, we observed increases in the macular thickness during the follow-up in the Infiniti group. These changes had no effect on the improvement of visual acuity after the cataract surgery, even though the differences reached the threshold of statistical significance in the Infiniti group instead of the Centurion group. It is still not clear that how cataract surgery affects retinal structure and microcirculation. We speculated that there were two reasons for the results. First, the increases of the macualr thickness may have resulted from the breakdown of the blood-retinal barrier with the gravity-fluidics configuration[8,28-29]. Second, the use of IOL may have stimulated the inflammatory cytokines in the vitreous[26]. Even though the same IOL was used in both groups, however, the differences did not reach the threshold of statistical significance, possibly due to the relatively minor changes in IOP in the Centurion group[30]. Therefore, the shorter operation time, less intraoperative injury, and the relatively minor changes in the IOP may have contributed to the lack of any significant increase in the macular thickness during the follow-up in the Centurion group.

A limitation of this study is the small sample size, and therefore, our results may have been biased by the short follow-up time. Further longitudinal studies involving larger numbers of patients are needed.

In conclusion, using the Infiniti phacoemulsification system, OCTA provided a promising analysis of retinal vascular alterations, demonstrating a reduction of the PVD and an increase in the macular thickness. The Centurion phacoemulsification system can provide better retinal vasculature preservation during cataract surgery.

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