



# Optic nerve head microvascular changes after phacoemulsification surgery

Müjdat Karabulut<sup>1</sup> · Sinem Karabulut<sup>1</sup> · Sabahattin Sül<sup>1</sup> · Aylin Karalezli<sup>1</sup>

Received: 16 April 2019 / Revised: 27 August 2019 / Accepted: 7 September 2019 / Published online: 16 September 2019  
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

## Abstract

**Background** To determine optic nerve head (ONH) microvascular changes detected by optical coherence tomography angiography (OCTA) and intraocular pressure changes (IOPs) after uncomplicated phacoemulsification surgery.

**Methods** The study was designed as a prospective observational study. Twenty-four eyes were included. Eyes with retinal vascular pathology, any type of age-related macular degeneration, IOP more than 21 mmHg, axial length less than 20 mm and more than 24 mm, corneal edema and cataracts that can disrupt images, and history of ocular surgery were excluded. Patients underwent OCTA imaging and IOP measurement preoperatively (baseline) and postoperatively (weeks 1 and 4). Vessel density % (VD) in the total disc, peripapillary, and inside disc were measured. IOP was measured with the applanation tonometer. Comparison of VD and IOP and correlation between VD and IOP change were determined.

**Results** VD was significantly increased in all quadrants in week 4 compared to those in week 1. In terms of VD and IOP, although there was no significant difference between week 1 and baseline, week 4 results were significantly different from baseline ( $p < 0.05$  and  $p < 0.001$ , respectively). The IOP was significantly lower in week 4 (14.8 mmHg) than in week 1 (16.0 mmHg) ( $p < 0.001$ ). There was a significant negative correlation between the inside disc and total VD and IOP at weeks 1 and 4.

**Conclusion** Phacoemulsification surgery can result in a decrease in IOP and an increase in VD of the ONH.

**Keywords** Optical coherence tomography angiography · Intraocular pressure phacoemulsification · Vessel density

## Introduction

Phacoemulsification is a cataract surgery technique that is frequently used and has very successful visual results. After cataract surgery, some changes in ocular hemodynamics and IOP have been reported in various studies [1, 2].

OCTA is a non-invasive and highly repeatable imaging technique that can show the peripapillary microvascular structure [3, 4].

This study aims to evaluate changes in the IOP and the VD of the optic nerve head after uncomplicated phacoemulsification surgery and to evaluate the correlation between them.

## Method

This study was designed as a prospective study. Twenty-four eyes from 24 patients who underwent uncomplicated phacoemulsification and intraocular lens (IOL) implantation surgery were included in the study. Maculopathies (hereditary or acquired), optic nerve head pathologies (tilted disc, drusen, optic disc edema, atrophy, etc.), optic neuropathies (demyelinating, infectious, ischemic, etc.), adjusted IOP for central corneal thickness more than 21 mmHg, axial length less than 20 mm and more than 24 mm, surgery-induced corneal edema and massive cataracts that can disrupt images, history of vasoactive agents (calcium antagonists, nitric oxide, etc.) use, systemic diseases (vasculitis, diabetes mellitus, hypertension, etc.) and any ocular surgery, complicated phacoemulsification surgeries, and images with motion or cataract-originated artifacts (signal strength index less than 60) were excluded. Full ophthalmologic examination and OCTA imaging were performed before (baseline) and after surgery (weeks 1 and 4). Imaging was performed using an RTVue-XR Avanti (Optovue, Inc., Fremont, CA, USA). Total, peripapillary,

---

This is to certify that the article has not been presented in a meeting

✉ Müjdat Karabulut  
mujdatkarabulut@gmail.com

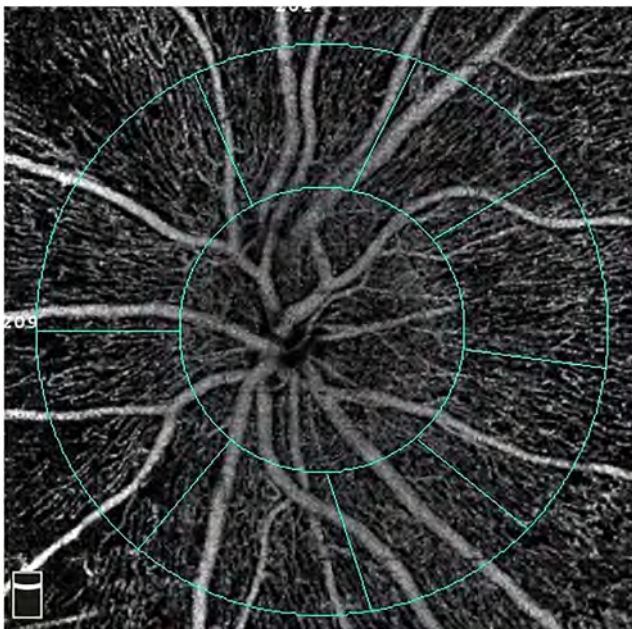
<sup>1</sup> Department of Ophthalmology, Mugla Sıtkı Koçman University Medical School, Mugla, Turkey

and inside disc VD was measured using a  $4.5 \times 4.5$ -mm scan that was centered on the ONH (Fig. 1). IOP was measured using applanation tonometry. Results from baseline, week 1, and week 4 were compared. The correlation between IOP and VD changes was evaluated. Data were analyzed using SPSS version 22.0.0.0 software (IBM Corporation and other(s)). Comparisons were performed using a paired *t* test, and correlations between the IOP and VD change were determined using the Pearson correlation coefficient (PCC). Statistical significance was defined as  $p < 0.05$ .

This study was approved by the Muğla Sıtkı Koçman University Clinical Research Ethics Committee. (decision number 08/VIII date 31/05/2018).

## Results

All the patients had grade 2 nuclear sclerosis. The standard phacoemulsification procedure was done using the Alcon CENTURION® Vision System (Alcon Laboratories Inc.) by a single surgeon. A clear, ultraviolet-absorbing, acrylate/methacrylate copolymer single-piece IOL (Alcon AcrySof® single-piece SA60AT, Alcon Laboratories Inc.) was implanted within the capsular bag. The mean objective surgical time was  $14.7 \pm 5$  min. The mean age was 65.4 years (range, 60–70 years). Eighteen male (81.8%) and four female (18.2%) patients were included in the study. The mean axial length was  $23 \pm 0.6$  mm. Total, peripapillary, inside disc VD of ONH, and IOP results are shown in Table 1. VD was significantly increased in all quadrants in week 4 compared to week



**Fig. 1** Angio-ONH (total, peripapillary, and inside disc) in a  $4.5 \times 4.5$ -mm scan size

**Table 1** Comparison of VD and IOP postoperatively

	Mean $\pm$ SD		<i>p</i> value
	Week 1	Week 4	
Density (%)			
Total disc	48.2 $\pm$ 1.7	49.4 $\pm$ 1.6	< 0.001
Peripapillary	50.1 $\pm$ 1.9	51.8 $\pm$ 2.4	< 0.001
Inside disc	50.2 $\pm$ 5.6	53.0 $\pm$ 5.4	< 0.001
IOP (mmHg)	16.0 $\pm$ 1.0	14.8 $\pm$ 0.8	< 0.001

Italicized entries mean statically significant *p* value

1 (Table 1). Moreover, the mean IOP was significantly lower in week 4 (14.8 mmHg) compared with week 1 (16.0 mmHg;  $p < 0.001$ ; Table 1). Figure 2 is showing dynamics of IOP before and after surgery. For VD and IOP, although there was no significant difference between week 1 and baseline, week 4 results were significantly different from baseline ( $p < 0.05$  and  $p < 0.001$ , respectively; Tables 2 and 3). There was also a negative correlation between the inside disc and total VD and IOP at weeks 1 and 4 (Table 4). Both superficial and deep retinal plexus VD were also increased in foveal, parafoveal, and perifoveal quadrants on a  $6.00 \times 6.00$ -mm macular-centered imaging.

## Discussion

The optic nerve head and retinal blood flow depend on the balance between arterial blood pressure and IOP. Although retinal blood flow is not significantly affected because of retinal autoregulation in moderate increases in the IOP, it can be inhibited completely at supra systolic IOP levels [5, 6].

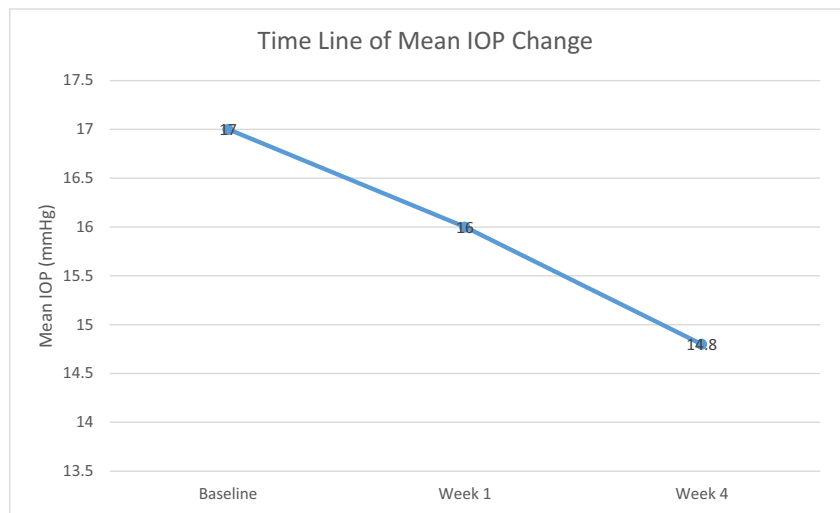
Several methods have been described to measure optic nerve head perfusion [7–9]. The ocular pulse amplitude (OPA) is defined as the difference between diastolic and systolic IOP. Pulsatile ocular blood flow in the choroid generates the ocular pulse, showing the choroidal blood flow indirectly, but not retinal blood flow [10, 11]. Color Doppler ultrasound can show retrobulbar vascular circulation but not ocular microcirculation [12].

Angiography can only show circulation in the superficial layers but not in the deep layers. Additionally, it is an invasive procedure and has an anaphylaxis risk [13].

The laser doppler flowmeter can detect microcirculation in a limited retinal area, and laser speckle flowgraphy can display only the flow rate [14, 15].

A scanning laser Doppler flowmeter can show only superficial vascularization of the optic nerve head and retina [16]. Magnetic resonance imaging cannot show the microvascular structures in the optic nerve head and retina because of

**Fig. 2** Dynamics of IOP before and after surgery



insufficient resolution [17]. Doppler Fourier domain OCT (Doppler FD-OCT) can show only large vessels but not microvascularization, and images are mostly affected by eye movements [18].

OCTA is a new, non-invasive imaging technique that uses motion contrast imaging to obtain high-resolution volumetric blood flow information and generate angiographic images in a matter of seconds. A split-spectrum amplitude-decorrelation angiography (SSADA) algorithm can be used to display local microcirculation. SSADA can measure both transverse and axial flow with the same sensitivity [19].

In many studies, the effects of cataract and cataract surgery on ocular hemodynamics have been reported. Hilton et al. found that OPA was lower in eyes with a cataract compared to healthy eyes, and it increased after surgery and correlated with IOP [2]. Similarly, Hopkins et al. reported that OPA was 20–30% lower in eyes with a cataract [20].

However, some studies showed no changes in ocular hemodynamics after cataract surgery. In these studies, Doppler USG which can only image substantial vascularization despite microvascular changes was used [21–23].

OCTA is a novel imaging technique, and very few reports about vascular changes after cataract surgery have been published. Studies with OCTA showed significantly increased

macular VD after cataract surgery [24]. However, in this study, only macular vascular changes were evaluated, not ONH vascularization.

In this study, VD was increased in all quadrants postoperatively. Although the VD increased dramatically in week 4 compared to baseline and week 1, the baseline and week 1 results were not significantly different compared to each other.

Although the exact mechanism remains unclear, the reduction in IOP after cataract surgery probably results from indirect factors that may contribute to facilitating aqueous humor drainage. An increase in the depth of the anterior chamber and the release of prostaglandin F-2 may facilitate drainage through the trabecular meshwork [25–27]. Additionally, an IOL placement, which increases the mechanical tension in the zonation region, may reduce the aqueous humor drainage resistance by expanding the trabecular meshwork space [27, 28]. In this study, the mean IOP decreased postoperatively. Although the mean IOP was significantly reduced in week 4 compared to baseline and week 1, there was no difference in the mean baseline and week 1 IOP results.

The effect of a change in IOP on ocular hemodynamics has been shown in many studies. Hilton et al. reported a negative correlation between OPA and IOP after cataract surgery [2].

**Table 2** Comparison of VD and IOP at baseline and week 1

	Mean ± SD		<i>p</i> value
	Baseline	Week 1	
Density(%)			
Total disc	47.8 ± 1.8	48.2 ± 1.7	0.377
Peripapillary	49.5 ± 1.9	50.1 ± 1.9	0.544
Inside disc	49.3 ± 5.3	50.2 ± 5.6	0.300
IOP (mmHg)	17.0 ± 1.2	16.0 ± 1.0	0.150

**Table 3** Comparison of VD and IOP at baseline and week 4

	Mean ± SD		<i>p</i> value
	Baseline	Week 4	
Density (%)			
Total disc	47.8 ± 1.8	49.4 ± 1.6	<i>0.002</i>
Peripapillary	49.5 ± 1.9	51.8 ± 2.4	<i>0.045</i>
Inside disc	49.3 ± 5.3	53.0 ± 5.4	< <i>0.001</i>
IOP (mmHg)	17.0 ± 1.2	14.8 ± 0.8	< <i>0.001</i>

Italicized entries mean statically significant *p* value

**Table 4** The mean increase in VD and decrease in IOP at week 1 and week 4, correlation between VD and IOP

Density (%)	Mean change $\pm$ SD					
	Total disc		Peripapillary		Inside disc	
	1.29 $\pm$ 1.14		1.47 $\pm$ 1.29		2.75 $\pm$ 2.95	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
IOP (mmHg) (mean change $\pm$ SD)	<i>-0.582</i>	<i>0.001</i>	<i>-0.128</i>	<i>0.318</i>	<i>-0.579</i>	<i>0.017</i>
	1.25 $\pm$ 1.11					

*p* *p* value, *r* Pearson's *r* correlation

Italicized entries mean statically significant *p* value

Zhao et al. reported that an increase in retinal vascular density might be associated with a decreased IOP. Similarly, we found a strong negative correlation between IOP and total VD and inside disc VD, but not peripapillary VD, postoperatively ( $r = -0.582$ ,  $p = 0.001$ ;  $r = -0.579$ ,  $p = 0.017$ ;  $r = -0.128$ ,  $p = 0.318$ , respectively). We thought these could be caused by the peripapillary blood supply and retinal vascular autoregulation that maintains an adequate blood supply in this area.

In conclusion, in this prospective study, we found a progressive increase in VD in ONH quadrants, except for the peripapillary area, and a decrease in IOP after cataract surgery. Additionally, there was a negative correlation between VD and IOP in the week 1 and 4 results. Novel imaging modalities such as OCTA will be useful to better explain the effect of cataract surgery on ocular hemodynamics. More reliable results can be obtained with a larger number of patients and longer postoperative follow-up.

## Compliance with ethical standards

**Conflict of interest** The authors declare that there is no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the (place name of institution and/or national research committee) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

## References

- Melancia D, Abegao Pinto L, Marques-Neves C (2015) Cataract surgery and intraocular pressure. *Ophthalmic Res* 53:141–148. <https://doi.org/10.1159/000377635>
- Hilton EJ, Hosking SL, Gherghel D, Embleton S, Cunliffe IA (2005) Beneficial effects of small-incision cataract surgery in patients demonstrating reduced ocular blood flow characteristics. *Eye* (London, England) 19:670–675. <https://doi.org/10.1038/sj.eye.6701620>
- Wylegala A, Teper S, Dobrowolski D, Wylegala E (2016) Optical coherence angiography: a review. *Medicine* 95:e4907. <https://doi.org/10.1097/md.0000000000004907>
- Spaide RF, Fujimoto JG, Waheed NK, Sadda SR, Staurenghi G (2018) Optical coherence tomography angiography. *Prog Retin Eye Res* 64:1–55. <https://doi.org/10.1016/j.preteyeres.2017.11.003>
- Schmidl D, Boltz A, Kaya S, Werkmeister R, Dragostinoff N, Lasta M, Polska E, Garhofer G, Schmetterer L (2012) Comparison of choroidal and optic nerve head blood flow regulation during changes in ocular perfusion pressure. *Invest Ophthalmol Vis Sci* 53:4337–4346. <https://doi.org/10.1167/iovs.11-9055>
- Guidoboni G, Harris A, Cassani S, Arciero J, Siesky B, Amireskandari A, Tobe L, Egan P, Januleviciene I, Park J (2014) Intraocular pressure, blood pressure, and retinal blood flow autoregulation: a mathematical model to clarify their relationship and clinical relevance. *Invest Ophthalmol Vis Sci* 55:4105–4118. <https://doi.org/10.1167/iovs.13-13611>
- Flammer J, Orgul S, Costa VP, Orzalesi N, Kriegelstein GK, Serra LM, Renard JP, Stefansson E (2002) The impact of ocular blood flow in glaucoma. *Prog Retin Eye Res* 21:359–393
- Shiose Y, Kitazawa Y, Tsukahara S, Akamatsu T, Mizokami K, Futa R, Katsushima H, Kosaki H (1991) Epidemiology of glaucoma in Japan—a nationwide glaucoma survey. *Jpn J Ophthalmol* 35:133–155
- Flammer J, Orgul S (1998) Optic nerve blood-flow abnormalities in glaucoma. *Prog Retin Eye Res* 17:267–289
- Langham ME, Farrell RA, O'Brien V, Silver DM, Schilder P (1989) Blood flow in the human eye. *Acta ophthalmol Suppl* 191:9–13
- Pekel G, Acer S, Cetin EN, Yagci R, Kasikci A, Cevik A (2015) Ocular pulse amplitude and retinal vessel caliber changes after intravitreal ranibizumab. *Int Ophthalmol* 35:657–662. <https://doi.org/10.1007/s10792-014-9991-z>
- Matthiessen ET, Zeitz O, Richard G, Klemm M (2004) Reproducibility of blood flow velocity measurements using colour decoded Doppler imaging. *Eye* (London, England) 18:400–405. <https://doi.org/10.1038/sj.eye.6700651>
- Hayreh SS (1972) Colour and fluorescence of the optic disc. *Ophthalmologica* 165:100–108. <https://doi.org/10.1159/000308475>
- Riva CE (2001) Basic principles of laser Doppler flowmetry and application to the ocular circulation. *Int Ophthalmol* 23:183–189
- Sugiyama T, Araie M, Riva CE, Schmetterer L, Orgul S (2010) Use of laser speckle flowgraphy in ocular blood flow research. *Acta Ophthalmol* 88:723–729. <https://doi.org/10.1111/j.1755-3768.2009.01586.x>
- Sehi M (2011) Basic technique and anatomically imposed limitations of confocal scanning laser Doppler flowmetry at the optic nerve head level. *Acta Ophthalmol* 89:e1–e11. <https://doi.org/10.1111/j.1755-3768.2009.01728.x>
- Prunte C, Flammer J, Markstein R, Rudin M (1995) Quantification of optic nerve blood flow changes using magnetic resonance imaging. *Invest Ophthalmol Vis Sci* 36:247–251
- Wang Y, Bower BA, Izatt JA, Tan O, Huang D (2008) Retinal blood flow measurement by circumpapillary Fourier domain Doppler optical coherence tomography. *J Biomed Opt* 13:064003. <https://doi.org/10.1117/1.2998480>
- Jia Y, Tan O, Tokayer J, Potsaid B, Wang Y, Liu JJ, Kraus MF, Subhash H, Fujimoto JG, Hornegger J, Huang D (2012) Split-spectrum amplitude-decorrelation angiography with optical coherence tomography. *Opt Express* 20:4710–4725. <https://doi.org/10.1364/oe.20.004710>
- Hopkins SD (1989) Ocular haemodynamics in cataractous eyes. A pilot study. *Acta ophthalmol Suppl* 191:43–48



21. ALP MN, DOĞAN B, TOLA M, YARANGÜMELİ A, ÖLÇER T, KURAL G (2004) Effect of cataract surgery on orbital blood flow in diabetic patients with nonproliferative retinopathy. *Journal of Retina-Vitreous* 12:189–194
22. Turk A, Mollamehmetoglu S, Imamoglu HI, Kola M, Erdol H, Akyol N (2013) Effects of phacoemulsification surgery on ocular hemodynamics. *Int J Ophthalmol* 6:537
23. Rainer G, Kiss B, Dallinger S, Menapace R, Findl O, Schmetterer K, Georgopoulos M, Schmetterer L (1999) Effect of small incision cataract surgery on ocular blood flow in cataract patients I. *J Cataract Refract Surg* 25:964–968
24. Zhao Z, Wen W, Jiang C, Lu Y (2018) Changes in macular vasculature after uncomplicated phacoemulsification surgery: optical coherence tomography angiography study. *J Cataract Refract Surg* 44:453–458. <https://doi.org/10.1016/j.jcrs.2018.02.014>
25. Mathalone N, Hyams M, Neiman S, Buckman G, Hod Y, Geyer O (2005) Long-term intraocular pressure control after clear corneal phacoemulsification in glaucoma patients. *J Cataract Refract Surg* 31:479–483. <https://doi.org/10.1016/j.jcrs.2004.06.046>
26. Poley BJ, Lindstrom RL, Samuelson TW (2008) Long-term effects of phacoemulsification with intraocular lens implantation in normotensive and ocular hypertensive eyes. *J Cataract Refract Surg* 34:735–742. <https://doi.org/10.1016/j.jcrs.2007.12.045>
27. Shrivastava A, Singh K (2010) The effect of cataract extraction on intraocular pressure. *Curr Opin Ophthalmol* 21:118–122. <https://doi.org/10.1097/ICU.0b013e3283360ac3>
28. Shingleton BJ, Pasternack JJ, Hung JW, O'Donoghue MW (2006) Three and five year changes in intraocular pressures after clear corneal phacoemulsification in open angle glaucoma patients, glaucoma suspects, and normal patients. *J Glaucoma* 15:494–498. <https://doi.org/10.1097/01.jig.0000212294.31411.92>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.