Int Ophthalmol (2019) 39:1081–1088
https://doi.org/10.1007/s10792-018-0919-x

ORIGINAL PAPER

Predictive value of spectral-domain optical coherence tomography features in assessment of visual prognosis in eyes with acute welding arc maculopathy

Chunxia Zhang · Guangfu Dang · Tianmei Zhao · DongLin Wang · Yan Su · Yi Qu

Received: 16 August 2017 / Accepted: 7 April 2018 / Published online: 12 April 2018

Abstract

Objective To observe spectral-domain optical coherence tomography (SD-OCT) features and to determine whether baseline OCT features can be used as predictors of visual acuity outcome in eyes with acute welding arc maculopathy.

Methods This retrospective study enrolled twenty-two eyes of eleven subjects with acute welding arc maculopathy. All subjects were evaluated by SD-OCT at baseline and final visit. The involved parameters included best-corrected visual acuity (BCVA), central macular thickness (CMT), the length of ellipsoid zone (EZ) defects, the greatest linear dimension (GLD) of outer retinal lesions, EZ reflectivity and relative EZ reflectivity (defined as the ratio of EZ reflectivity to retinal pigment epithelium reflectivity on OCT).

Results Acute welding arc maculopathy was presented as abnormal hyperreflectivity, hyporeflectivity and defects of outer retinal layer in fovea on OCT. Compared with baseline, BCVA improved significantly accompanied by decreased GLD of outer retinal lesions and the length of EZ defects at final visit ($P = 0.0004$, $P < 0.0001$ and $P < 0.0001$, respectively). No significant changes were shown on CMT ($P = 0.248$). In multivariate regression analysis, final BCVA was associated with baseline BCVA and the length of EZ defects ($P = 0.012$ and $P = 0.045$, respectively). However, EZ reflectivity and relative EZ reflectivity were not associated with final BCVA ($P > 0.05$).

Conclusion In conclusion, SD-OCT images clearly reveal morphological changes in outer retinal layer in acute welding arc maculopathy. The baseline BCVA and length of EZ defects are the strongest predictors of final BCVA.

Keywords Welding arc maculopathy · Spectral-domain optical coherence tomography · Ellipsoid zone · Visual acuity

C. Zhang · Y. Qu (✉)
Department of Geriatrics, QiLu Hospital of Shandong University, No. 107, Wenhuaxi Road, Jinan 250012, China
e-mail: sdfzzcx@126.com

C. Zhang · T. Zhao · D. Wang · Y. Su
Department of Ophthalmology, Jinan Mingshui Eye Hospital, Jinan 250200, China

G. Dang
Department of Ophthalmology, Qianfoshan Hospital Affiliated with Shandong University, No. 16766, Jingshi Road, Jinan 250014, China

Introduction

Phototoxic maculopathy resulting from exposure to electric welding arcs is typically characterized by photochemical damage to outer retinal layers and has a permanent damage in subjects with more extensive exposure. As the outer retinal layer is an avascular

structure, fundus examination by indirect ophthalmoscope and fundus fluorescein angiography (FFA) has limitations to evaluate microanatomy changes. The advent of optical coherence tomography (OCT), especially high-resolution spectral-domain optical coherence tomography (SD-OCT), provides a fast, simple and noninvasive method to assess retinal structures at microscopic level [1]. OCT features in patients with welding arc maculopathy have been reported, but not so commonly and all of them were case reports [2–5]. To the best of our knowledge, there have been few reports concerning the changes in visual acuity (VA) over time and no reports concerning predictive factors for visual outcome. In this study, we aimed to observe retinal morphological changes on OCT, final visual outcome, and to evaluate the predictive value of clinical parameters and morphologic features on OCT at baseline in assessment of visual prognosis at final visit.

Subjects and methods

Subjects

This retrospective study included 22 eyes of 11 consecutive patients with acute welding arc maculopathy who visited Jinan Mingshui Eye Hospital between August 2009 and January 2015. The study adhered to the tenets of the Declaration of Helsinki and was approved by the local institutional ethics committee of Jinan Mingshui Eye Hospital. Criteria for inclusion were: (1) decreased VA attributable to exposure to welding arc; (2) the duration of symptoms at baseline no more than 1 month; and (3) phototoxic maculopathy confirmed with OCT. Patients were excluded from this study if they had any of the following: (1) presence of other macular diseases; (2) a history of severe systemic problems.

Examinations

At baseline, all participants received comprehensive ophthalmologic examinations including BCVA measured using a standard decimal visual acuity chart, converted to the logarithm of minimal angle resolution (logMAR) equivalent, slit-lamp biomicroscopy examinations, dilated fundus examination by indirect ophthalmoscope and color fundus photography, FFA (HRA-2, Heidelberg Engineering, Heidelberg, German) and spectral-domain optical coherence tomography (SD-OCT, Spectralis, Heidelberg Engineering, Inc., Heidelberg, Germany).

Central macular thickness (CMT), the length of ellipsoid zone (EZ) defects and the greatest linear dimension (GLD) of outer retinal lesions were measured on OCT images with internal caliper software [1, 6–8] (Fig. 1a, b). CMT was manually calculated at the fovea by horizontal scan, measuring the distance between Bruch membrane and the internal limiting membrane [6]. EZ reflectivity and relative EZ reflectivity (defined as the ratio of EZ reflectivity to retinal pigment epithelium (RPE) reflectivity) measurements were made on ImageJ [9, 10] (National Institutes of Health, Bethesda, MD; available at http://rsb.info.nih.gov/ij/index.html) (Fig. 1c, d). All measurements were performed by two independent, experienced investigators who were masked to patient information, and average of the two measurements was recorded for analysis. If the measurements differed by greater than 15%, a final measurement was agreed after open arbitration by a third senior examiner. All patients had undergone follow-up examinations for at least 1 month; best-corrected visual acuity (BCVA) and OCT were obtained in all patients at every visit.

Statistical analyses

Statistical analyses were performed using SPSS version 21.0 (SPSS for windows, version 19.0, SPSS Inc., Chicago, IL). Distribution of normality was assessed using Shapiro–Wilk test. Paired t test was performed for comparing continuous variables between baseline and final visit. Univariate and multivariate regression analyses were performed to identify factors associated with final BCVA. P value less than 0.05 was considered statistically significant.

Results

Baseline characteristics

This study involved 22 eyes of 11 male patients with bilateral acute welding arc maculopathy, with a mean age of 49.77 $\pm$ 8.25 years (range 34–62 years). Mean follow-up period was 4.27 $\pm$ 1.16 months. Color fundus photographs showed a round yellowish foveal

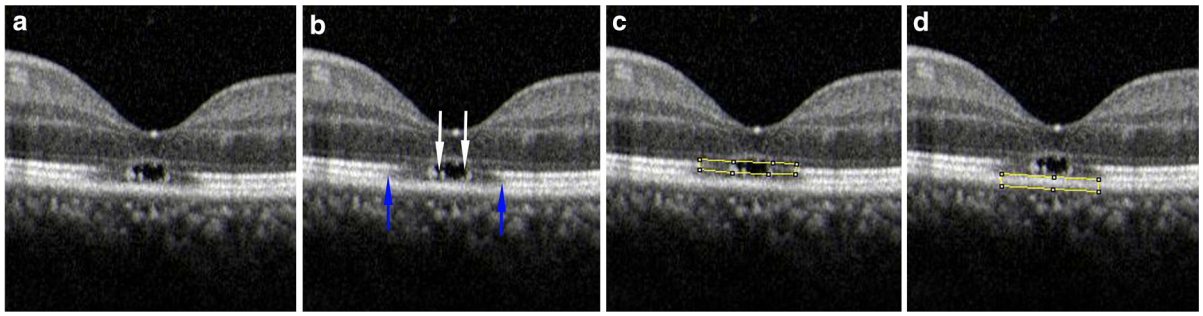

Fig. 1 Example of the length of EZ defects, GLD of outer retinal lesions, EZ reflectivity and relative EZ reflectivity on OCT. OCT of the left eye of a 35-year-old man showed hyporeflectivity in OS, disrupture of EZ, OS and IZ, and a cyst formed like space between ELM and RPE (**a**). The length of EZ defects (white arrow) and GLD of outer retinal lesions (blue arrow) were measured on OCT images with internal caliper software (**b**). EZ reflectivity in lesions (**c**) and corresponding RPE reflectivity (**d**) were made on ImageJ. Relative EZ reflectivity was defined as the ratio of EZ reflectivity to RPE reflectivity

spots with an obscure boundary in 20 eyes (90.9%) (Fig. 2a). After 1 month, yellowish foveal spots completely disappeared in 4 eyes (Fig. 2b). At the outer edges of yellowish foveal spots, a yellow–white halo was observed in 2 eyes (9.1%) (Fig. 2c). Fluorescein angiography was normal without hyperfluorescence or hypofluorescence in fovea in all eyes.

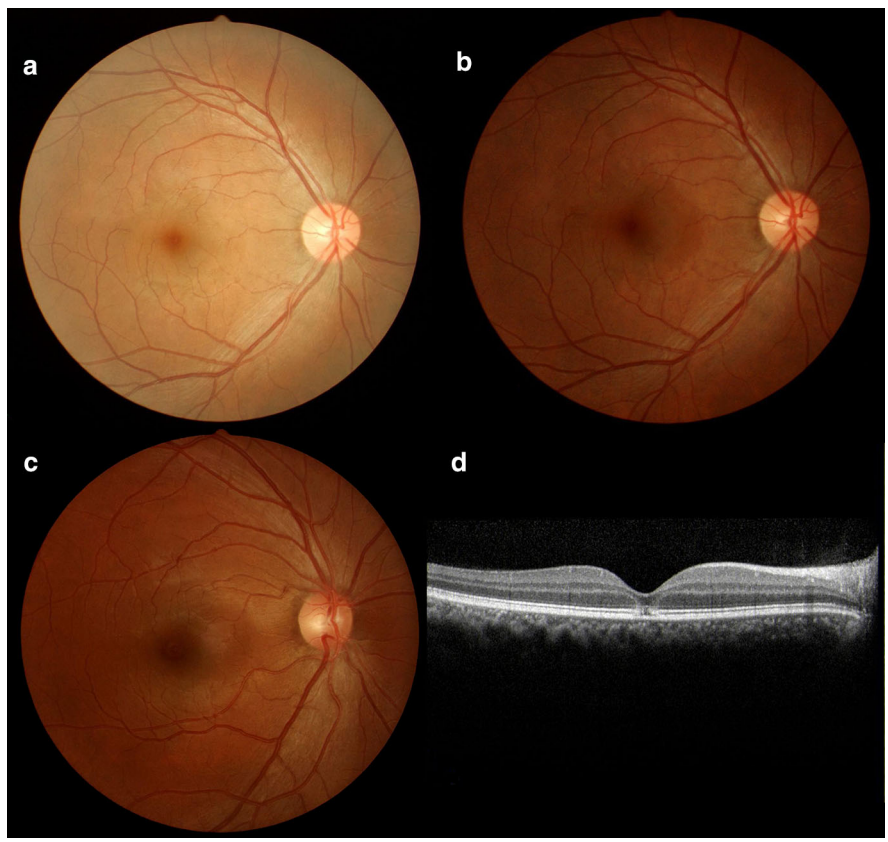

Fig. 2 Foveal retinal lesions in color fundus photographs and OCT features of two patients with acute welding arc maculopathy. Color fundus photographs of the right eye of patient 1 showed a round yellowish foveal spots with an obscure boundary (**a**). After 1 month, yellowish foveal spots completely disappeared (**b**). Color fundus photographs of the right eye of patient 2 showed a yellow–white halo at the outer edges of yellowish foveal spots (**c**). Defect of EZ, OS and IZ, and a "V"-type particle-like hyperreflectivity linked with OPL were observed in corresponding OCT (**d**)

Morphological changes on OCT

OCT image revealed the presence of morphological changes in fovea in 21 eyes (95.5%) and meta-nasal to the fovea in 1 eye (0.5%). In 11 eyes (50%), the outer retina showed disruptions of EZ, outer segments of photoreceptors (OS) and interdigitation zone (IZ), and a cyst formed like space between the external limiting membrane (ELM) and RPE (Fig. 3a). Hyporeflectivity in OS and defect of IZ were observed in 8 eyes (36.4) (Fig. 3b). A distinct discontinuity of EZ and defect of OS and IZ were observed in 6 eyes (27.3%) (Fig. 3c). Defect of EZ, OS and IZ, and a "V"-type particle-like hyperreflectivity linked with outer plexiform layer (OPL) were observed in 2 eyes (9.1%) (Fig. 2d). Defect of OS and IZ, and an enhanced "column" particle-like hyperreflection of outer nuclear layer (ONL) and EZ were observed in 2 eyes (9.1%) (Fig. 3e). Symmetry changes in both eyes were observed in 16 eyes (72.7%). ELM and RPE layer remained intact at the site of outer retinal lesions in all eyes. The reduced outer retinal lesions in size and restoration of EZ, OS and IZ at each visit were accurately documented with OCT (Fig. 3c, d, f–h).

Changes in BCVA and quantitative analysis of OCT features

The mean BCVA improved significantly at final visit compared with baseline ($P = 0.0004$). No significant difference was found on CMT at final visit compared with baseline ($P > 0.05$). GLD of outer retinal lesions and the length of EZ defects decreased significantly at final visit compared with baseline ($P < 0.0001$ and $P < 0.0001$, respectively) (Table 1).

Predictor of visual activity outcome

In univariate regression analysis, final BCVA significantly correlated with baseline BCVA ($t = 7.040$,

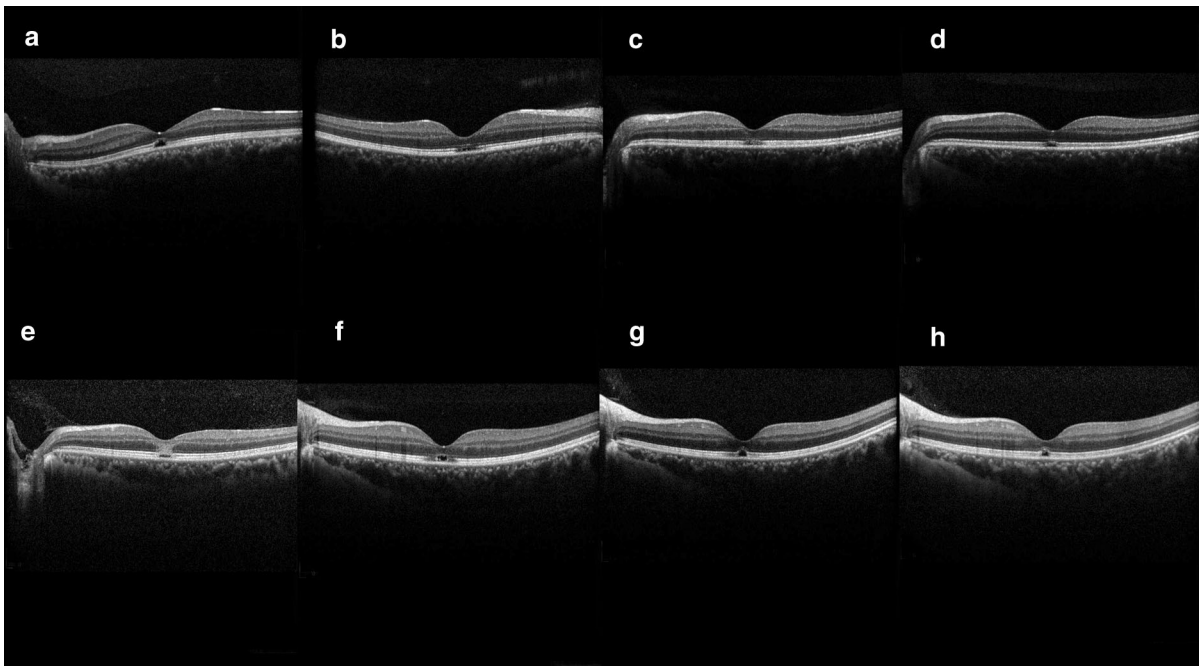

Fig. 3 SD-OCT showed morphological changes in outer retinal layers. Disruptions of EZ, OS and IZ, and a cyst formed like space between ELM and RPE (**a**). Hyporeflectivity in OS and defect of IZ (**b**). OCT of the left eye of patient 3 showed a distinct discontinuity of EZ and defect of OS and IZ (**c**). GLD of outer retinal layer lesion decreased from 232.60 μm at baseline (**c**) to 24 μm at 1 month (**d**). Defect of OS and IZ, and an enhanced "column" particle-like hyperreflection of ONL and EZ (**e**). OCT of the left eye of patient 4 showed hyporeflectivity in OS, disrupture of EZ, OS and IZ, and a cyst formed like space between ELM and RPE (**f**). Three months later hyporeflectivity in OS gradually restored (**g**). GLD of outer retinal lesion decreased from 336.48 μm at baseline (**f**) to 188.00 μm at 3 months (**g**) and 75.98 μm at 6 months (**h**).The length of EZ defect decreased from 92.32 μm at baseline (**f**) to 76.40 μm at 3 months (**g**) and 60.12 μm at 6 months (**h**)

Table 1 Mean BCVA, CMT, GLD of outer retinal lesions and the length of EZ defects evaluated during the follow-up period

Parameter	Baseline	Final visit	*t*	*t*
BCVA, LogMAR (Snellen)	0.38 ± 0.13 (20/100–20/25)	0.31 ± 0.11 (20/66–20/25)	4.123	0.0004
CMT, um	206.64 ± 9.81	208.00 ± 9.57	1.188	0.248
GLD, um	474.00 ± 268.81	152.64 ± 71.90	6.741	< 0.0001
EZ, um	241.77 ± 110.93	110.23 ± 68.42	9.257	< 0.0001

BCVA best-corrected visual acuity, *LogMAR* logarithm of minimal angle resolution, *CMT* central macular thickness, *GLD* greatest linear dimension, *EZ* ellipsoid zone

$P < 0.0001$), GLD of outer retinal lesions ($t = 7.017$, $P < 0.0001$) and the length of EZ defects ($t = 5.351$, $P < 0.0001$). In multivariate stepwise regression analysis, final BCVA was associated with baseline BCVA ($t = 2.786$, $P = 0.012$) and the length of EZ defects ($t = 2.152$, $P = 0.045$). However, EZ reflectivity and relative EZ reflectivity were not associated with final BCVA (all $P > 0.05$, Table 2).

Discussion

In this study, we used SD-OCT to observe retinal morphological changes, quantitatively evaluate OCT features, and its relation to visual activity outcome in patients with acute welding arc maculopathy. SD-OCT showed morphological changes in outer retinal layers. Compared with baseline, BCVA improved significantly accompanied by decreased GLD of outer retinal lesions and the length of EZ defects at final visit. In multivariate regression analysis, final BCVA was associated with baseline BCVA and the length of EZ defects.

Electrical welding arcs emit an intense and extended spectrum of radiation ranging from infrared (IR) to ultraviolet (UV). UV and far-IR radiation are absorbed by the cornea and the lens, whereas visible light, near-IR radiation and intensive near-UV emissions penetrate deep into the retina. If sufficient in intensity, they may cause thermal or photochemical retinal damage, which may be permanent and sight threatening [2–4]. Welding arc maculopathy usually occurs in young apprentice welders who are at increased risk of retinal injury because of their presumably clear ocular media and occupational inexperience [2]. As these retinal lesions are typically

Table 2 Univariate and multivariate regression analyses of the influence on final BCVA of clinical parameters and OCT features of patients with acute welding arc maculopathy

Factor	Univariate analysis		Multivariate analysis	
	Correlation coefficient	*P* value	Regression coefficient B	*P* value
Age at onset, year	0.809	0.428		
Baseline BCVA, LogMAR	7.040	< 0.0001	2.786	0.012
Baseline CMT, um	1.903	0.072		
Baseline GLD, um	7.017	< 0.0001	0.487	0.632
The lengths of EZ defect	5.351	< 0.0001	2.152	0.045
EZ reflectivity	0.119	0.906		
Relative EZ reflectivity	0.718	0.481		
Follow-up duration	1.358	0.189		

BCVA best-corrected visual acuity, *LogMAR* logarithm of minimal angle resolution, *CMT* central macular thickness, *GLD* greatest linear dimension, *EZ* ellipsoid zone

small, they are difficult to identify and document clinically. The use of OCT has been reported as effective methods for documenting outer retinal layer changes with this type of injury [2, 3]. In this study, fluorescein angiogram appeared normal, whereas OCT demonstrated disruption of photoreceptor layers. Thus, OCT is more sensitive to tiny morphological macular changes to examine the fundus of patients with welding arc maculopathy.

Phototoxic maculopathy was divided into two grades as the following: Defect of EZ was defined as Grade 1 maculopathy and interruption of EZ and RPE layer was defined as Grade 2 maculopathy [4]. In our study, the outer retinal lesions were induced by welding arc among which visible light, especially blue, and UV with a short wavelength were the primary units after a long-time exposure. Therefore, outer retinal damage in this study belonged to the injury of Grade 1 mainly with discontinuity of EZ. Our OCT findings demonstrated focal hyporeflectivity at the level of outer retinal layer, possibly due to direct photoreceptor phototoxicity, the indirect effects of retinal pigment epithelium phototoxicity, or both effects. The hyperreflectivity of outer retinal layer presumably represents cellular debris. During the follow-up period, we observed that photoreceptor layer lesion gradually restored starting from the periphery to the center. An interesting speculation based on OCT findings in our case is that acute photochemical injury may lead to reversible perturbation in photoreceptor outer segment renewal process.

According to some studies, the EZ is formed by the reflectivity generated from the high mitochondrial density of the outermost portion of the inner photoreceptor segments [11]. The EZ was previously known as the junction of the inner and outer photoreceptor segments (IS/OS junction) [12]. Some studies have performed qualitative analyses of EZ defects in many retinal conditions, and it appeared that its disruption was correlated with poor vision [13–15]. The integrity of outer retinal layers was highly associated with rapid and significant BCVA improvement, which could be easily detected by spectral-domain OCT in eyes with macular edema due to central retinal vein occlusion (CRVO) [16]. Chatziralli et al. [17] reported that disruption of EZ was associated with poor visual acuity in patients with retinal vein occlusion (RVO). Consistent with previous studies [16, 17], BCVA decreased accompanied by disrupture of EZ [2], and the presence of EZ defects was associated with unfavorable visual results. We hypothesize that the morphologic changes at the microstructural level from more extensive exposure may lead to irreversible damage of photoreceptors. In addition, no evidence was detected on central macular thickness to support phototoxic maculopathy which could be associated with macular edema or macular atrophy in a short-term observation.

Experimental quantifications on SD-OCT images were performed in a few studies, and the potential benefit of this approach in predicting visual outcomes was underlined [18–20]. Some studies have performed quantitative analyses of EZ defects and suggested that preoperative lengths of EZ defects were associated with visual outcome in patients undergoing macular hole (MH) surgery. To the best of our knowledge, there have been no reports concerning the prognostic correlation between clinical parameters, the length of EZ defects, GLD of outer retinal lesions and visual outcome in patients with welding arc maculopathy. For the first time, our study showed that baseline BCVA and the length of EZ defects are predictors of visual outcome in patients with acute welding arc maculopathy.

Although disruption of EZ has been qualitatively and quantitatively analyzed and reported to be a predictor of poor visual acuity in various maculopathies [7, 12–14], the variation in reflectivity of the outer retinal layers has rarely been investigated quantitatively [15–17]. As shown recently, there has been a relationship between EZ reflectivity on OCT and cone density in the perifoveal area [18]. In this study, we investigated the relationship between EZ reflectivity and relative EZ reflectivity on OCT and visual outcome. However, our study showed no association between EZ reflectivity, relative EZ reflectivity and final BCVA, suggesting that EZ reflectivity and relative EZ reflectivity are not prognostic factors for visual outcome.

Our study had several limitations. The sample size examined by OCT was relatively small, and the evaluated time point was different and not long enough because of the retrospective characteristic of this study. The data of subfoveal choroidal thickness were not on show because enhanced depth imaging OCT (EDI-OCT) was not used.

In conclusion, SD-OCT images clearly revealed morphological changes in outer retinal layer in acute welding arc maculopathy. The baseline BCVA and the length of EZ defects are the strongest predictors of final BCVA. Long-term and large-scale prospective investigation is needed in the future.

Compliance with ethical standards

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

Ethical approval The study has been approved by the local institutional ethics committee of Jinan Mingshui Eye Hospital and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

References

1. Houly JR, Veloso CE, Passos E, Nehemy MB (2017) Quantitative analysis of external limiting membrane, ellipsoid zone and interdigitation zone defects in patients with macular holes. Graefes Arch Clin Exp Ophthalmol 255(7):1297–1306. https://doi.org/10.1007/s00417-017-3636-7
2. Mahindrakar A, Toshniwal S, Doongerwala MI, Anthony H (2013) Spectralis optical coherence tomography findings in Welder's maculopathy. Indian J Ophthalmol 61(5):238–240. https://doi.org/10.4103/0301-4738.113318
3. Jabbarpoor Bonyadi MH (2013) Early and late spectral domain optical coherence tomography features of acute welding maculopathy. J Ophthalmic Vis Res 8(4):391–392
4. Yang X, Shao D, Ding X, Liang X, Yang J, Li J (2012) Chronic phototoxic maculopathy caused by welding arc in occupational welders. Can J Ophthalmol 47(1):45–50. https://doi.org/10.1016/j.jcjo.2011.12.001
5. Hiesch A, Berrot A, Quintyn JC (2011) Unilateral photic maculopathy caused by welder's flash. J Fr Ophtalmol 34(1):37 e31–37 e37. https://doi.org/10.1016/j.jfo.2010.09.013
6. Iacono P, Battaglia Parodi M, Iuliano L, Bandello F (2018) How vitreomacular interface modifies the efficacy of anti-vegf therapy for myopic choroidal neovascularization. Retina 38(1):84–90. https://doi.org/10.1097/IAE.0000000000001500
7. Grewal DS, Reddy V, Mahmoud TH (2015) Assessment of foveal microstructure and foveal lucencies using optical coherence tomography radial scans following macular hole surgery. Am J Ophthalmol 160(5):990–999 e991. https://doi.org/10.1016/j.ajo.2015.08.014
8. Cheng Y, Li Y, Huang X, Qu Y (2017) Application of optical coherence tomography angiography to assess anti-vascular endothelial growth factor therapy in myopic choroidal neovascularization. Retina. https://doi.org/10.1097/IAE.0000000000002005
9. Flores M, Debellemaniere G, Bully A, Meillat M, Tumahai P, Delbosc B, Saleh M (2015) Reflectivity of the outer retina on spectral-domain optical coherence tomography as a predictor of photoreceptor cone density. Am J Ophthalmol 160(3):588–595 e582. https://doi.org/10.1016/j.ajo.2015.06.008
10. Bae K, Cho GE, Yoon JM, Kang SW (2016) Optical coherence tomographic features and prognosis of pneumatic displacement for submacular hemorrhage. PLoS ONE 11(12):e0168474. https://doi.org/10.1371/journal.pone.0168474
11. Staurenghi G, Sadda S, Chakravarthy U, Spaide RF (2014) Proposed lexicon for anatomic landmarks in normal posterior segment spectral-domain optical coherence tomography: the IN*OCT consensus. Ophthalmology 121(8):1572–1578. https://doi.org/10.1016/j.ophtha.2014.02.023
12. Srinivasan VJ, Monson BK, Wojtkowski M, Bilonick RA, Gorczynska I, Chen R, Duker JS, Schuman JS, Fujimoto JG (2008) Characterization of outer retinal morphology with high-speed, ultrahigh-resolution optical coherence tomography. Invest Ophthalmol Vis Sci 49(4):1571–1579. https://doi.org/10.1167/iovs.07-0838
13. Oster SF, Mojana F, Brar M, Yuson RM, Cheng L, Freeman WR (2010) Disruption of the photoreceptor inner segment/outer segment layer on spectral domain-optical coherence tomography is a predictor of poor visual acuity in patients with epiretinal membranes. Retina 30(5):713–718. https://doi.org/10.1097/IAE.0b013e3181c596e3
14. Maheshwary AS, Oster SF, Yuson RM, Cheng L, Mojana F, Freeman WR (2010) The association between percent disruption of the photoreceptor inner segment-outer segment junction and visual acuity in diabetic macular edema. Am J Ophthalmol 150(1):63–67 e61. https://doi.org/10.1016/j.ajo.2010.01.039
15. Landa G, Su E, Garcia PM, Seiple WH, Rosen RB (2011) Inner segment-outer segment junctional layer integrity and corresponding retinal sensitivity in dry and wet forms of age-related macular degeneration. Retina 31(2):364–370. https://doi.org/10.1097/IAE.0b013e3181e91132
16. Wolf-Schnurrbusch UE, Ghanem R, Rothenbuehler SP, Enzmann V, Framme C, Wolf S (2011) Predictors of short-term visual outcome after anti-VEGF therapy of macular edema due to central retinal vein occlusion. Invest Ophthalmol Vis Sci 52(6):3334–3337. https://doi.org/10.1167/iovs.10-6097
17. Chatziralli I, Theodossiadis G, Chatzirallis A, Parikakis E, Mitropoulos P, Theodossiadis P (2017) Ranibizumab for retinal vein occlusion: predictive factors and long-term outcomes in real-life data. Retina. https://doi.org/10.1097/IAE.0000000000001579
18. Barthelmes D, Sutter FK, Kurz-Levin MM, Bosch MM, Helbig H, Niemeyer G, Fleischhauer JC (2006) Quantitative analysis of OCT characteristics in patients with achromatopsia and blue-cone monochromatism. Invest Ophthalmol Vis Sci 47(3):1161–1166. https://doi.org/10.1167/iovs.05-0783

19. Mataftsi A, Schorderet DF, Chachoua L, Boussalah M, Nouri MT, Barthelmes D, Borruat FX, Munier FL (2007) Novel TULP1 mutation causing leber congenital amaurosis or early onset retinal degeneration. Invest Ophthalmol Vis Sci 48(11):5160–5167. https://doi.org/10.1167/iovs.06-1013

20. Barthelmes D, Gillies MC, Sutter FK (2008) Quantitative OCT analysis of idiopathic perifoveal telangiectasia. Invest Ophthalmol Vis Sci 49(5):2156–2162. https://doi.org/10.1167/iovs.07-0478