



# Anatomical and functional features of photic retinopathy: a spectral domain optical coherence tomography–based longitudinal study

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## Abstract

**Background** Photic retinopathy may lead to permanent foveal structural injury, leading to irreversible visual acuity loss.

**Method** This prospective observational study evaluated 51 eyes of 30 patients with photic retinopathy. Optical coherence tomography (OCT) imaging was performed for all the eyes at baseline and final follow-up. All the eyes showed a focal outer retinal defect on spectral-domain OCT (SD-OCT) at the junction of the inner and outer photoreceptor segments. SD-OCT was used to measure central macular thickness, maximum horizontal dimension of the defect, maximum defect thickness, and the photic retinopathy index (PRI) through the foveal raster scan.

**Results** Although PRI improved significantly at the final follow-up from baseline with a 17% improvement in PRI after a period of 6 months in photic retinopathy eyes, visual acuity declined for 14% of the patients and was stable for 84%. There was mild correlation of visual acuity with baseline PRI. Baseline PRI was significantly higher in eyes with poorer presenting visual acuity (VA). In total, 33.3% of the eyes showed partial ellipsoid zone recovery at 6 months. The area under curve of the receiver operator characteristic curve for partial ellipsoid zone recovery with the mean baseline PRI as the independent variable was poor at 0.612.

**Conclusion** OCT-based ultrastructural features in photic retinopathy seem to have poor correlation with presenting or final visual acuity. To the best of our knowledge, this is the largest study on longitudinal OCT evaluation of photic retinopathy eyes in literature.

**Keywords** Solar retinopathy · Photic retinopathy · OCT · Prognosis · Ellipsoid zone · Follow-up

## Introduction

### Key messages

- Photic retinopathy eyes may show an outer retinal defect on optical coherence tomography,
- OCT based ultrastructural features may help prognosticate patients of photic retinopathy.
- Photic retinopathy index can be used to understand the longitudinal follow-up of photic retinopathy eyes.

The neurosensory retina is extremely sensitive to high intensities of light, with toxic levels leading to photic retinopathy. Although sunlight is the most common cause of photic retinopathy, newer causes like welding

light and laser pointers are increasingly becoming common today. The first cases of photic maculopathy were described with sungazing or solar eclipse viewing, and hence the term “solar retinopathy” and “eclipse retinopathy” have become synonymous to each other. However, the clinical presentation of such patients is quite variable, which makes determination of incidence or prevalence of the disease difficult. Stokkermans and Dunbar have described an incidence of 0.14% in

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patients visiting a non-specialized eye care center [1]. Solar retinopathy may be associated with sungazing in mental disorders, and in subjects using psychotropic drugs, or sensitizing medications [2]. Eclipse-induced retinopathy is usually bilateral and asymmetric. Patients generally present with bilateral asymmetric blurring of vision, scotoma, metamorphopsia, or afterimages/photopsias [3–5]. After the advent of modern high-resolution optical coherence tomography, specific ultrastructural features of photic retinopathy have been described [6–10]. Spectral-domain optical coherence tomography (OCT) studies have observed that eyes undergo the following changes; in the acute phase, hyperreflective areas appear to be extending from the outer retinal layer to the inner layers, which in the chronic phase get substituted by a hyporeflective cyst-like space in the ellipsoid zone, indicating photoreceptor damage [11, 12]. Mostly photic retinopathy patients do not require treatment; while some clinicians prefer starting steroids, there is no consensus for the same. The visual prognosis of photic retinopathy is generally good, with majority of the eyes recovering the lost visual acuity or maintaining the same [13]. This study was planned to understand the ultrastructural features of the eyes presenting with clinically diagnosed photic retinopathy and confirmed on OCT imaging, and to try and describe prognostic features of anatomical and functional improvement on longitudinal follow-up.

## Methods

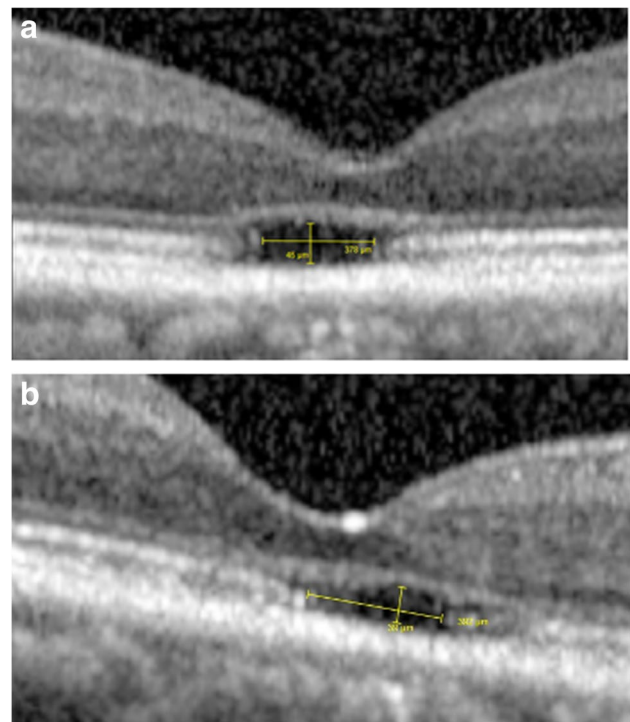
This prospective observational study was conducted in the retina clinic of a tertiary care eye center in South India on patients of photic retinopathy who presented to the center between June 2017 and June 2019. The study was conducted after taking clearance from the Institutional Review Board and the study adhered to the tenets of the Declaration of Helsinki. All the patients gave informed consent before being included in this study.

A clinical diagnosis of photic retinopathy based on history of exposure to sunlight, eclipse, or welding light with the naked eye, followed by development of complaint of a scotoma in the visual field or frank diminution of visual acuity, was confirmed by the presence of an outer retinal defect in the ellipsoid zone on OCT in all the affected eyes. At diagnosis, all the patients underwent a complete ophthalmological examination including visual acuity using the Snellen chart, intraocular pressure, and slit-lamp biomicroscopy. SD-OCT (Spectralis HRA HD-OCT, Heidelberg Engineering) (16 horizontal raster scan) was performed in both eyes of each patient to evaluate the ultrastructural changes in each eye. Patients

also underwent fundus autofluorescence imaging. All the patients received antioxidant medication and were followed up every 2 months until a period of 6 months. SD-OCT was repeated at 6 months to analyze the longitudinal ultramicroscopic changes.

The parameters measured on SD-OCT were central macular thickness (CMT), maximum defect thickness (vertical depth), and maximum horizontal dimension of the outer retinal defect at the scan through the fovea, and these were measured from the images taken both at baseline and at 6-month follow-up (Fig. 1). “Photic retinopathy index” or PRI was obtained by dividing the maximum defect thickness in the foveal scan with the CMT (Fig. 1). All measurements were recorded by two independent graders and the readings were averaged to obtain the final value. The overall status of the ellipsoid zone (EZ) at fovea and whether it showed partial recovery at the final follow-up was also documented.

Data were entered into a Microsoft Excel Spreadsheet and analyzed using SPSS version 20.0 (IBM Inc.). Qualitative variables were expressed as mean  $\pm$  standard deviation and categorical variables as percentages. Comparison of variables was performed using the t test for parametric data and Mann–Whitney U test for non-parametric data. A *p* value of less than 0.05 was considered as the significance level.



**Fig. 1** **a** and **b** demonstrate the measurement of maximum defect thickness and horizontal dimensions of the outer retinal defect in eyes with photic retinopathy

**Table 1** Clinical profile of all eyes of Photic retinopathy included in the study

Sl no	Age	Sex	Etiology	Laterality	Days to presentation	Baseline VA	Final VA	CMT	Baseline defect parameters			Final defect parameters	Partial EZ recovery	Baseline PRI	Final PRI
									Maximum horizontal dimension	Maximum depth	Maximum thickness				
1	62	F	sun gazing	unilateral	4	6/12 (p)	6/18.	291	242	76	244	76	-	0.261	0.261
2	42	M	sun gazing	bilateral	3	6/6.	6/6.	207	51.5	23.5	60	11	+	0.114	0.053
3						6/12.	6/12.	175.5	133	41	61	27	-	0.234	0.154
4	30	M	sun gazing	bilateral	5	6/9(p)	6/12.	358.5	316	62	313	54	+	0.173	0.151
5						6/9(p)	6/12.	346.5	169	71	160	62.5	+	0.205	0.180
6	46	M	welding work	bilateral	7	6/6(p)	6/6 (p)	215	311.5	55	313	55	-	0.256	0.256
7						6/6	6/6.	181	516.5	30	520	30	-	0.166	0.166
8	63	M	welding work	unilateral	15	6/24.	6/24.	220.5	526	65	530	63.5	-	0.295	0.288
9	62	F	sun gazing	unilateral	20	6/12(p)	6/18.	289.5	241	76	244	76	-	0.263	0.263
10	60	F	solar eclipse	bilateral	20	6/12.	6/12.	219.5	362	49	296	43.5	-	0.223	0.198
11						6/12.	6/12.	215	488	62	376	41	-	0.288	0.191
12	25	M	solar eclipse	bilateral	10	6/12.	6/12.	224	201.5	46	282	34.5	-	0.205	0.154
13						6/12(p)	6/12(p)	224.5	176.5	47.5	137	34	+	0.212	0.151
14	48	M	sun gazing	bilateral	8	6/12(p)	6/12(p)	180	226	52	185	43	-	0.289	0.239
15						6/6(p)	6/6(p)	211	185.5	26	275	27	+	0.123	0.128
16	63	M	sun gazing	unilateral	12	6/6(p)	6/6(p)	222	125.5	26	120	24.5	-	0.117	0.110
17	36	M	sun gazing	bilateral	5	6/6.	6/6.	265.5	178.5	26	177	23	-	0.098	0.087
18						6/6.	6/6.	293.5	122.5	27	124	24.5	-	0.092	0.083
19	22	F	sun gazing	bilateral	7	6/6.	6/6.	231	159.5	23	160	23	-	0.100	0.100
20						6/6	6/6.	224.5	121	26	120	26.5	-	0.116	0.118
21	51	F	sun gazing	unilateral	5	6/36.	6/18.	194	236	51	174	35	+	0.263	0.180
22	46	M	sun gazing	bilateral	10	6/24	6/24.	220.5	202	30	185	30	-	0.136	0.136
23						6/6	6/6.	262	262.5	34	200	29	-	0.130	0.111
24	21	M	sun gazing	bilateral	5	6/6.	6/6.	246.5	437	56	385	48	+	0.227	0.195
25						6/6	6/6.	254.5	551.5	67	487	54.5	+	0.263	0.214
26	31	M	welding	bilateral	10	6/9.	6/12.	252.5	221	30	187	30	-	0.119	0.119
27						6/9	6/12.	255	186.5	67	207	73	-	0.263	0.286
28	36	M	welding	bilateral	16	6/18.	6/18.	295.5	221	62	200	50	-	0.210	0.169
29						6/18	6/18.	290.5	262	52.5	250	44.5	-	0.181	0.153

Table 1 (continued)

Sl no	Age	Sex	Etiology	Laterality	Days to presentation	Baseline VA	Final VA	CMT	Baseline defect parameters	Final defect parameters	Partial EZ recovery	Baseline PRI	Final PRI	
									Maximum horizontal dimension	Maximum horizontal dimension	Maximum depth	Maximum depth	Maximum thickness	
30	28	M	welding	bilateral	8	6/18.	6/18.	188	435	57	385	48	0.303	0.255
31						6/18.	6/18.	188.5	550	67.5	487	54	0.358	0.286
32	39	F	welding	unilateral	6	6/9.	6/9.	231.5	88	67	73	46	0.289	0.199
33	35	M	sungazing	bilateral	6	6/6.	6/6.	229.5	251.5	35	200	26	0.153	0.113
34						6/9.	6/9.	219	292.5	38.5	225	26.5	0.176	0.121
35	40	M	sungazing	bilateral	5	6/9.	6/9.	255	251.5	43	220	30.5	0.169	0.120
36						6/9.	6/9.	241	285	44	235	45	0.183	0.187
37	35	M	welding	bilateral	6	6/6.	6/6.	231.5	252	35	200	26	0.151	0.112
38						6/9.	6/9.	219	292	38	225	25	0.174	0.114
39	64	M	welding	unilateral	10	6/6.	6/6.	263	276	25	130	20	0.095	0.076
40	30	M	sungazing	bilateral	5	6/12.	6/12.	242.5	316.5	62.5	295	61	0.258	0.252
41						6/12.	6/12.	252	168.5	73	169	73	0.290	0.290
42	40	M	sungazing	bilateral	10	6/6.	6/6.	257	534	40	610	56	0.156	0.218
43						6/12.	6/12.	251.5	520.5	57	502	44	0.227	0.175
44	43	M	sungazing	unilateral	12	6/6.	6/6.	234.5	158.5	26	150	21	0.111	0.090
45	56	M	welding	bilateral	16	6/6.	6/6.	196.5	221	30	187	30	0.153	0.153
46						6/6.	6/6.	247.5	187	67	207	72	0.271	0.291
47	51	F	welding	bilateral	10	6/9.	6/9.	211	250	43	220	30	0.204	0.142
48						6/9.	6/9.	221.5	284.5	45	235	44.5	0.203	0.201
49	39	F	welding	unilateral	4	6/9.	6/12.	243.5	88.5	68	73	47	0.279	0.193
50	27	F	welding	bilateral	6	6/6.	6/6.	225.5	133	37	130	29	0.164	0.129
51						6/6.	6/6.	225.5	122	33	120	32.5	0.146	0.144

VA visual acuity, M male, F female, CMT central macular thickness, EZ Ellipsoid zone, PRI photic retinopathy index

**Table 2** Agreement between two raters

Variable	ICC	<i>p</i> value
CMT	0.998	<0.0001
Horizontal dimension at baseline	0.999	<0.0001
Vertical dimension at baseline	0.996	<0.0001
Horizontal dimension at 6 months	0.999	<0.0001
Vertical dimension at 6 months	0.997	<0.0001
PRI at baseline	0.996	<0.0001
PRI at final	0.996	<0.0001

ICC intra-class correlation

## Results

### Demography and clinical presentation

The current study evaluated 51 eyes of 30 subjects with photic retinopathy (Table 1). The mean age of the study population was  $42.4 \pm 13.22$  years (range, 21–64 years; median = 40 years). A total of 27 eyes had solar retinopathy, 4 eyes had eclipse retinopathy, and 20 eyes had welder's arc retinopathy. The subjects presented to the retina clinic within an average time period of  $8.9 \pm 4.7$  days (median, 7.5 days; range, 3–20 days). The most common presenting symptoms were absolute scotoma (42 eyes, 51%), followed by diminution of vision (21 eyes, 41.2%). Twenty-one patients had bilateral retinopathy and 9 had unilateral. A total of 20 eyes had 6/6 Snellen visual acuity at presentation. On examination, all the eyes had normal anterior segment findings. In total, 47/51 eyes showed an altered foveal reflex on fundus examination. All the eyes showed a focal outer retinal defect on SD-OCT at the junction of inner and outer photoreceptor segments, involving the fovea. The vitreoretinal interface showed no abnormality in the eyes, and the retinal pigment epithelium and the choriocapillaris were structurally normal. In the region of the outer retinal defect, all the eyes showed a disruption of EZ and interdigitation zone.

All measurements of CMT, maximum horizontal dimension of defect, and maximum defect thickness through the foveal scan were performed by 2 independent graders (K.A., S.S.). The agreement analysis between the two graders has been summarized in Table 2. The

central macular thickness at fovea at baseline was  $238.05 \pm 37.6$   $\mu\text{m}$ . The average horizontal dimension of the defect reduced from  $262.55 \pm 132.38$   $\mu\text{m}$  at baseline to  $240.2 \pm 129.46$   $\mu\text{m}$  at final follow-up ( $p = 0.39$ ). The average maximum defect thickness reduced from  $46.88 \pm 16.4$   $\mu\text{m}$  at baseline to  $40.79 \pm 16.57$   $\mu\text{m}$  at final follow-up ( $p = 0.06$ ).

We compared the recovery of the maximum defect thickness and horizontal dimension of the defect at final follow-up with baseline. In 17 eyes (33.3%) showing partial EZ recovery, the horizontal dimension improved from  $260.44 \pm 158.93$   $\mu\text{m}$  at baseline to  $240.76 \pm 163.34$   $\mu\text{m}$  at final follow-up ( $p = 0.72$ ), and maximum defect thickness improved from  $44.35 \pm 16.54$   $\mu\text{m}$  at baseline to  $37.09 \pm 14.67$   $\mu\text{m}$  at final follow-up ( $p = 0.18$ ). In 34 eyes without any EZ recovery, the horizontal dimension improved from  $263.6 \pm 119.59$   $\mu\text{m}$  at baseline to  $239.9 \pm 111.6$   $\mu\text{m}$  at final follow-up ( $p = 0.4$ ) and the maximum defect thickness improved significantly from  $48.15 \pm 16.45$  at baseline to  $42.65 \pm 17.34$  at final follow-up ( $p = 0.18$ ).

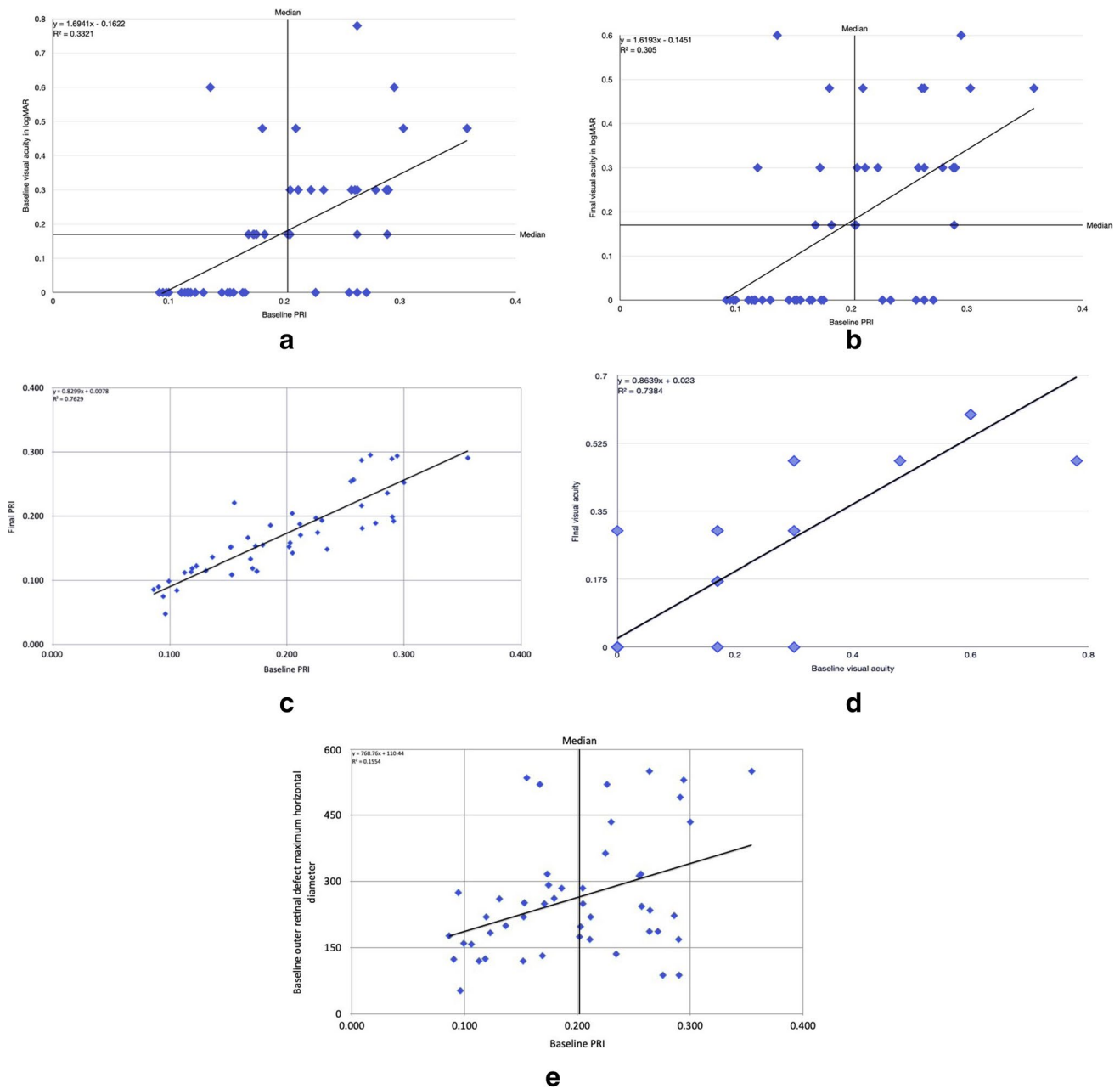
The baseline photic retinopathy index was measured as  $0.199 \pm 0.068$  and the final PRI at 6 months follow-up was  $0.172 \pm 0.064$  ( $p = 0.04$ ). At baseline, a total of 33 eyes had VA of  $\geq 6/9$  with an average PRI of  $0.17 \pm 0.06$  (median, 0.167), while 18 eyes (35.3%) had VA  $< 6/9$  with an average PRI of  $0.248 \pm 0.05$  (median, 0.257) ( $p < 0.001$ ). Baseline PRI was significantly higher in eyes with poorer presenting VA. None of the eyes had worse than 6/36 Snellen VA at baseline.

A summary of the final VA status is summarized in Table 3. Final VA of  $\geq 6/9$  was seen in 28 eyes (54.9%), whose average baseline PRI was  $0.167 \pm 0.06$  (median, 0.155) and final VA  $< 6/9$  was seen in 23 eyes (45.1%) with average baseline PRI of  $0.209 \pm 0.06$  (median, 0.211) ( $p = 0.021$ ). Hence, the eyes with higher baseline PRI seemed to have poorer final VA. Figure 2a and b demonstrate the linear regression between baseline logMAR VA and final logMAR VA with PRI respectively. The  $R^2$  in Fig. 2a was 0.3 and that of Fig. 2b was 0.33, indicating that the correlation of PRI with visual acuity was not strong. Figure 2c demonstrates the correlation between baseline and final PRI and we found a strong correlation ( $R^2 = 0.76$ ), indicating that the baseline defect morphology affected the final anatomical status. Moreover, this linear regression also suggested a 17% improvement in PRI after a period of 6 months in photic retinopathy eyes. We also performed a linear regression between baseline and final VA and observed that the  $R^2$  was 0.74, indicating a similar strong correlation (Fig. 2d).

A total of 17 eyes (33.3%) showed a partial EZ recovery at 6 months. Baseline VA of better than or equal to 6/9 Snellen was seen in 13/17 eyes (76.4%) of the

**Table 3** Visual acuity at final follow-up

Remained stable	43/51, 84.3%
Worsened 1 line	7/51, 13.7%
Improved 2 line	1/51, 1.9%



**Fig. 2** **a** Correlation between baseline PRI and baseline visual acuity of patients. **b** Correlation between baseline PRI and final follow-up visual acuity of patients. **c** Correlation between baseline PRI and final

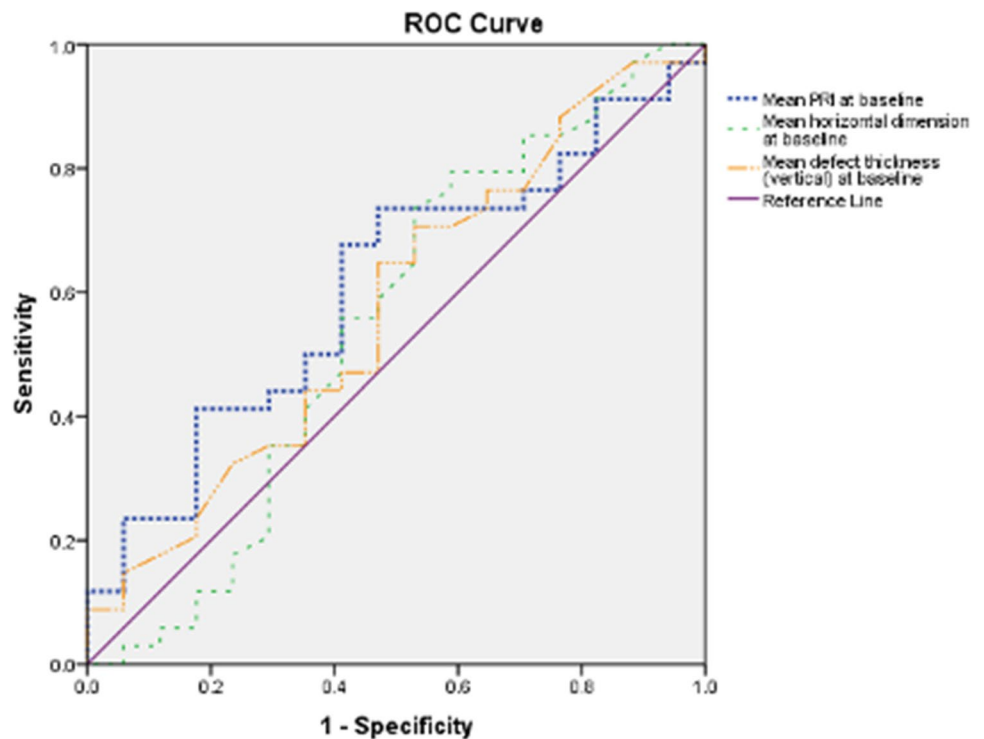
PRI. **d** Correlation between baseline visual acuity and final visual acuity. **e** Correlation between baseline PRI and baseline maximum horizontal dimension of outer retinal defect

eyes showing partial EZ recovery, and in 15/34 (55.9%) eyes in the eyes without EZ recovery. Eyes showing partial EZ recovery had a baseline average PRI of  $0.18 \pm 0.06$  (median, 0.169) which was not significantly different from eyes without EZ recovery (final PRI average =  $0.207 \pm 0.07$ , median = 0.205) ( $p = 0.18$ ). We also compared the baseline horizontal dimension between the groups and found no significant difference ( $p = 0.8$ ). We

observed that baseline PRI showed a weak positive correlation with baseline horizontal dimension of the outer retinal defect ( $R^2 = 0.155$ ) (Fig. 2e). Further correlations were performed between baseline horizontal dimension and baseline VA ( $R^2 = 0.05$ ) and final VA ( $R^2 = 0.02$ ), which were quite weak.

We performed a ROC analysis with partial EZ recovery as the dependent variable and baseline PRI as the

**Fig. 3** Receiver operator characteristic curve for partial ellipsoid zone recovery with independent variables—mean horizontal dimension of defect at baseline (AUC=0.549), mean defect thickness (vertical) at baseline (AUC=0.574), and mean baseline PRI (AUC=0.612). The AUC was maximum for mean baseline PRI



determinant variable, and found that the area under curve for baseline PRI was 0.612 signifying a poor discriminant function (95% CI = 0.453 – 0.772) (Fig. 3). At a cutoff value for baseline PRI of 0.173, the sensitivity and specificity for the discriminant function of baseline PRI towards partial EZ recovery were 67.6% and 58.8%. Eyes which had PRI of less than or equal to 0.173 ( $n = 22$ ) had a final VA of  $0.084 \pm 0.175$  logMAR and eyes which had PRI of more than 0.173 ( $n = 29$ ) had a final VA of  $0.247 \pm 0.188$  logMAR ( $p = 0.003$ ). The comparison of final VA in these two groups was statistically significant.

## Discussion

Outer retinal defect in photic retinopathy is a pathognomonic feature for clinching the diagnosis, and is said to be quite specific [14, 15]. The authors have shown that all photic retinopathy-affected eyes may show this defect, associated with foveal atrophy and abnormalities in photoreceptor cells and retinal pigment epithelium at the fovea [7, 16]. To date, there is no consensus regarding treatment of photic retinopathy eyes, and probably the long-term overall prognosis without any therapy is also optimal. Some cases may have persistent vision loss along with central scotoma over prolonged periods of time, although studies have shown that most cases may

recover completely within a few weeks or months [17, 18]. Most of the eyes tend to maintain the visual acuity after initial diminution to around 6/12. We observed that 64.7% of the current study eyes presented with equal to or better than 6/9 Snellen VA at baseline and none of the rest of the eyes had worse than 6/36 Snellen VA. A total of 84.3% of total eyes showed no change in VA at the final follow-up, while 13.7% eyes showed worsening.

Authors have seen that VA improvement may begin from the first week to 10 days after the insult, and may continue to improve until 6 months, after which the VA may become stationary [2, 13, 18]. Similar to observations regarding persistent VA loss, the outer retinal defect may also persist up to 1 year in almost 80% of the eyes, with only a few patients showing complete healing after 1 year [13, 19–21]. SD-OCT helps in diagnosing and following up these eyes longitudinally and may also help in prognosticating the eyes. VA has been previously correlated with foveal thickness, and tissue disruption [7, 22, 23]. Interestingly, subjective VA improvement may be reported despite persistence of ellipsoid zone defect on OCT, even after 50 years of exposure, and visual acuity may not always correlate with structural findings [7, 24, 25]. It is also believed that different outcomes in the eyes in terms of rapid VA recovery and persistent dysfunction may be dependent on the degree

of initial exposure, geographic location, retinal pigmentation, etc. [26].

In our study, we found that final visual acuity depended on baseline visual acuity. There was somewhat of a weak correlation between PRI and visual acuity (Figs. 1 and 2); however, VA correlated even more weakly with the horizontal dimension of the defect ( $R^2 \sim 0.02\text{--}0.05$ ). Moreover, the PRI also correlated very weakly with the horizontal dimension of the defect, indicating that PRI and maximum defect thickness may be better predictors of visual acuity. Around 33% eyes (1/3) may show recovery of EZ disruption after 6 months, with a statistically significant recovery of PRI by 17%. The PRI may be used to understand the magnitude of the initial insult of photic retinopathy and how much visual morbidity may occur in the long run. However, in our study subjects, visual acuity declined for 14% of the patients and was stable for 84% (1 patient had 2-line vision gain). PRI value of more than 0.173 may have prognostic value for visual outcome; however at a AUC value of 0.612 in our dataset, currently, we cannot conclude the same with strong confidence. Unless stronger data is shown in the future, as of now we might infer that OCT-based ultrastructural features in photic retinopathy have poor correlation with presenting or final visual acuity.

PRI may be an indirect marker of tissue loss, since it is a proportion of the patient's central macular thickness. Although over a prolonged period of follow-up partial recovery of ellipsoid zone may be noted, and the horizontal dimension of the defect may reduce, we did not observe any significant reduction in the PRI in these eyes, indicating again the poor correlation between horizontal dimension and maximum defect thickness in terms of recovery.

The limitations of our study are that most of the patients presented days to weeks later; hence, the OCT manifestation may mostly reflect late changes. Moreover, the period of follow-up is relatively short and longer periods of time may be required to effectively understand the final anatomical and functional outcome of photic retinopathy eyes. However, the strength of the study is that the patients were followed up regularly and a uniform follow-up is available for all patients.

Based on our results, it will be precarious to assume that one may estimate the extent of horizontal tissue defect and EZ disruption by measuring the PRI (since the correlation was weak). However, our study is novel in that we have developed an index for characterization of the disease based on OCT ultrastructural findings, apart from the other commonly used parameter, that is EZ disruption, and this needs to be further characterized in larger sample size studies with longer periods of follow-up. Also, to the best of our knowledge, this is the

largest series of OCT-based documentation of longitudinal follow-up of photic retinopathy eye reported to date.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s00417-021-05228-7>.

**Author contribution** KK: concept design, data collection and analysis, final approval. SS: concept design, data collection and analysis, final approval. KA: data collection and analysis, drafting manuscript, final approval. RPR: concept design, data collection and analysis, final approval. NBK: data collection and analysis, final approval. KR: concept design, final approval.

**Data availability** Will be made available on request.

## Declarations

**Ethics approval** This study was reviewed and approved by the Ethics Committee of the Aravind Eye Hospital.

**Informed consent** Patients were not required to give informed consent to the study because the analysis used anonymous clinical data that were obtained after each patient agreed to treatment by written consent.

**Consent for publication** All the authors have given their consent for publication and authorship.

**Conflict of interest** The authors declare no competing interests.

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