Posterior Pole Retinal Abnormalities in Mild Asymptomatic FEVR

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Familial exudative vitreoretinopathy (FEVR) is a hereditary disorder that was first described by Criswick and Schepens in 1969. It exhibits variable phenotypes among different individuals, patients from the same family, and even between the two eyes of one individual. Clinically, the peripheral retinal avascular zone, arteriovenous or venous-venous shunt formation, loops, vitreous adherence, retinal folds, temporal ectopia of the macula, retinal breaks, rhegmatogenous, and/or exudative retinal detachment are the most common clinical features of FEVR. Several posterior pole features have been described such as deformation of the vascular network and temporal ectopia of the macula, similar to the posterior pole in retinopathy of prematurity (ROP). Due to the slowly progressive nature of this disease, finding early stage FEVR is very important to facilitate which patients should receive timely examinations and treatments.

According to Pendergast and Trese, mild FEVR (stage I and II) are characterized by a peripheral avascular retina zone or retinal neovascularization at the junction of vascular and avascular areas. These patients were always difficult to identify due to lack of symptoms, and their posterior retinas are usually unremarkable. Thus, it is very important to find some “clues” in the easily examined posterior pole area in these patients. In recent years, some abnormalities have been reported in the posterior area of mild asymptomatic FEVR patients, such as the architecture of the vessels, and the increased distance from the macula fovea to the optic disc. However, such abnormalities are often subtle and easy to overlook by visual observation or conventional retinal image inspection. In this study, we investigated the imaging features in the posterior retinas of asymptomatic FEVR individuals with normal visual function, and compared them with those in healthy control eyes.

Materials and Methods

This study was conducted in accordance with the tenets of the Declaration of Helsinki. All procedures were approved by the Investigational Review Board of Zhongshan Ophthalmic Center, Sun Yat-sen University. Informed consent was obtained after explaining the nature and the possible consequences of this study. Thirty-eight FEVR patients and 38 controls were included in this study. A standard medical investigation was performed in each subject, consisting of a general history including gestational age, birth weight, and family history. The duration of pregnancy and neonatal birth weight was determined to exclude the possible presence of ROP. The ophthalmic examination included the best corrected visual acuity (BCVA), refractive status, axial length by A scan, slit lamp examination, and a fundus examination in full mydriasis with special attention to the vascularity of the peripheral retinas.

We classified FEVR according to Pendergast and Trese’s approach. Digital fundus photography (FP; Topcon Retinal Imaging System, Tokyo, Japan) was acquired in each subject. All images were analyzed for retinal vascular abnormalities. The vascular segmentation was performed using a software program (Vision Analysis System, Topcon, Tokyo, Japan). The vascular area was calculated, and the vascular density was determined as the percentage of the area of the vascular segment divided by the total area of the fundus. The vascular density was compared between FEVR and control groups. The vascular density was also compared between different stages of FEVR.

Results

Significant anatomic differences were identified in the eyes of patients with asymptomatic FEVR compared with those of the control subjects. In individuals with stage I or II FEVR, DD was smaller (1605.34 ± 250.60 vs. 1733.39 ± 163.79 μm), DM was larger (5434.08 ± 824.82 vs. 4696.29 ± 257.54 μm), and DM/DD was higher (3.49 ± 0.93 vs. 2.73 ± 0.28) than those of the controls. Peripapillary retinal vessels were increased significantly in FEVR compared with the controls (24.53 ± 3.10 vs. 21.39 ± 2.65).

Conclusions

Asymptomatic individuals with stage I or II FEVR had several abnormalities in the posterior pole noted with more retinal vessels, a significantly larger disc-to-macula distance as well as a remarkably smaller optic disc with a decreased horizontal diameter. These findings will facilitate the early diagnosis of FEVR and are important for adequate genetic counseling as well as the prevention and treatment of this disease.

Keywords: FEVR, posterior retina, image analysis

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Camera TRC 50DX; Topcon Corp., Tokyo, Japan) and fluorescein fundus angiography (FFA; Heidelberg HRA SPECTRALIS/ HRA2; Heidelberg Engineering, Heidelberg, Germany) were performed in all FEVR individuals and controls. All clinical data were obtained by an experienced ophthalmologist. Thirty-eight mild FEVR (stages I and II) individuals, with conventional "normal-appearing" posterior poles, were included in this study. The inclusion criteria in this study were as follows:

1. All FEVR patients had a positive family history of severe FEVR with bilateral retinal folds in first degree relatives. Among them, 30 cases were parents of severe FEVR kids, two cases were sons/daughters, and two cases were siblings of severe FEVR patients.
2. All individuals with FEVR were confirmed by the presence of peripheral small vessel abnormalities, including a peripheral avascular zone with an abrupt termination of the retinal capillary network, occlusion of the capillary bed resulting in aneurysm-like capillary endings, small areas of nonperfusion, small patches of neovascular proliferations, early arteriovenous shunt formation, or diffuse leakage of dye in FFA examination (Fig. 1).
3. Best corrected visual acuity in all mild FEVR patients was 20/20 or more.

All FEVR patients with obvious macular dragging or proliferative findings, such as vitreous hemorrhage and tractional retinal detachment were excluded. In individuals with bilateral mild FEVR, considering the symmetric nature of this disease, one of the eyes was randomly selected and used in the study. Thirty-eight healthy control eyes confirmed by FFA were enrolled, including the fellow healthy eyes of 14 cases with unilateral central serious chorioretinopathy, 12 cases with idiopathic choroidal neovascularization, and 12 eyes from 12 normal individuals who received examination as parents of FEVR kids. Besides, candidates with more than −6.00 D myopia were excluded since high myopia alone may cause peripheral avascularity and a relatively tilted disc.

**Preparation of Digital Images for Analysis**

All fundus photography and FFA images were reviewed by two observers (MY, YY). For digital imaging and morphometry of the fundus, a computer workstation was used. The observers were not informed about the clinical data, group information for the patients, and the peripheral fundus photos. For each retina studied, the photograph “most centered” in the picture was chosen to ensure the best view of both the optic disc and macular area.

**Measurement of Disc Size and Disc-to-Fovea Distance**

The horizontal disc diameter ($D_h$) and vertical disc diameter ($D_v$) were measured on FP. The disc diameter (DD) is
calculated as \((D_h + D_v)/2\) (Fig. 2). The center of the disc (D) and the center of the macula (M) were identified. The disc-to-macula distance (DM) in this study was the point-to-point distance from the center of the disc to the center of the macular fovea, which was modified from that used in Boonstra’s study.\(^5\) The center of fovea was determined on FP and the foveal avascular zone on FFA images. The ratio of DM/DD is defined as the ratio of the disc-to-fovea distance (DM) to the average of the horizontal and vertical DDs, \((D_h + D_v)/2\), which has been shown to be a valuable tool in diagnosing mild optic nerve hypoplasia and subtle macular dragging\(^6\) (Fig. 2). All the measurements were done using the default measuring program in a commercial retinal camera (Topcon Corp.).

Quantification of Posterior Retinal Vessels

In our previous study (under review), we developed a quantitative method to count the posterior retinal vessels. To quantify the retinal vessels, two circles and two arcs were used in each picture, including the peripapillary inner reference circle (PIRC), peripapillary outer reference circle (PORC), peripapillary temporal inner arc (PTIA), peripapillary temporal outer arc (PTOA), shown in Figure 3. The circle diameters were based on the actual horizontal width measurement of the optic disc. The retinal vessels crossing each circle/arc were counted and recorded. The preliminary results showed excellent intra-observer and interobserver agreement in all four parameters. Moreover, values of PIRC and PORC, PTIA and PTOA were highly correlated, respectively. Thus, the inner circles and arc, PIRC and PTIA were qualified to quantify the posterior retinal vessels radiated from the optic disc, and then employed in this present study (Fig. 4).

Intra- and Interobserver Agreement Study

All the parameters were measured or counted twice by each observer. The intra- and interobserver agreements were high. Intraclass correlation coefficient ranged from 0.890 to 0.999, demonstrating great repeatability for both observers in the crossing vessels \(D_h, D_v\), and DM. Since all the data met normal contribution, Pearson correlation was done to identify whether the results of these two observers could make an agreement. The \(r\) value in PIRC, PTIA, \(D_h, D_v\), and DM were from 0.837 to 0.999 \((P < 0.001)\), showing a trend toward a high interobserver agreement.

Statistics

The demographic features were analyzed with frequency and descriptive statistics. A \(\chi^2\) test was used to identify whether the sex and laterality were both matched between the mild FEVR individuals and the controls. The Shapiro-Wilk test was employed to verify whether the age, refractive status, axial length of the subjects, and the PIRC, PTIA, \(D_h, D_v\), DM, DD, and DM/DD results met normal distribution. An independent \(t\)-test was applied to compare the differences between the FEVR
group and the control group when the data were normally distributed, while the Wilcoxon Rank Sum test was adopted when they were not. All data were processed and analyzed in R (version 3.1.1). A statistical value of \( P < 0.05 \) was considered statistically significant.

**RESULTS**

There were no statistical differences in sex \( (P = 0.250) \); age \( (P = 0.054) \); laterality \( (P = 0.359) \); refractive status \( (P = 0.613) \); and axial length \( (P = 0.195) \) between the mild FEVR group and healthy control group. The demographic and clinical data are summarized in Table 1.

### TABLE 1. Demographic and Ocular Features of Mild FEVR Individuals and Controls

<table>
<thead>
<tr>
<th></th>
<th>FEVR, ( n = 38 )</th>
<th>Control, ( n = 38 )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>32.50 ± 10.12</td>
<td>37.58 ± 11.41</td>
<td>0.054</td>
</tr>
<tr>
<td>Sex, ( n ) (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18 (47.4)</td>
<td>23 (60.5)</td>
<td>0.250</td>
</tr>
<tr>
<td>Female</td>
<td>20 (52.6)</td>
<td>15 (39.3)</td>
<td></td>
</tr>
<tr>
<td>Laterality, ( n ) (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>17 (44.7)</td>
<td>21 (55.3)</td>
<td>0.359</td>
</tr>
<tr>
<td>OS</td>
<td>21 (55.3)</td>
<td>17 (44.7)</td>
<td></td>
</tr>
<tr>
<td>Refractive status, D</td>
<td>-0.125 (−5.75, 1.75)</td>
<td>-0.08 ± 1.61</td>
<td>0.613</td>
</tr>
<tr>
<td>Axial length, mm</td>
<td>24.21 ± 0.77</td>
<td>24.00 ± 0.66</td>
<td>0.195</td>
</tr>
</tbody>
</table>

Since the age and the axial length of two groups as well as the refractive status of the control group met normal distribution, the mean ± SD was used, while the median, the minimum, and the maximum were employed for the refractive status of the FEVR group, which did not met normal distribution. For comparison of the age and the axial length between two groups, an independent \( t \)-test was used. For comparison of the refractive status, the Wilcoxon Rank Sum test was applied. And for the sex and the laterality, a \( \chi^2 \) test was adopted \( (\alpha = 0.05) \).

### Comparison of DD, Disc-to-Macula Distance, and DM/DD Ratio

The mean optic DD was 1605.34 ± 250.60 \( \mu \text{m} \) in the FEVR group and 1733.39 ± 163.79 \( \mu \text{m} \) in the control group, respectively, with a statistically significant difference \( (P = 0.011) \). The difference was contributed mainly by a relatively smaller horizontal DD in FEVR individuals \( (P = 0.001) \), as the two groups' vertical DD was similar without statistical difference \( (P = 0.214) \). The mean DM was 5434.08 ± 824.82 \( \mu \text{m} \) in the FEVR group, which was obviously larger than that in the controls \( (P < 0.001) \). Moreover, the DM/DD ratio was significantly higher in the FEVR group \( (P < 0.001) \), due to both a smaller DD and a larger DM. The results are shown in Table 2.

### Comparison of the Retinal Vessels in the Posterior Pole

The mean vessel numbers on PIRC and PTIA in the individuals with FEVR were 24.53 ± 3.10 and 10.68 ± 1.76, which were both larger than in the controls \( (21.39 ± 2.65 \text{ and } 7.68 ± 2.67) \).
Ectopia, and bilateral retinal detachments leading to blindness. Clinically, many mild FEVR individuals are asymptomatic with good visual function. However, FEVR in some patients is slowly progressive, and finally may lead to retinal detachment. Thus, early stage FEVR is very important to diagnose to ensure patients to receive timely treatments and lifelong monitoring. However, due to the absence of any clinical symptoms, and the normal appearance of posterior poles, mild FEVR (stage I and II patients), is not easy to detect, nor to correctly diagnose. In our study, all 38 FEVR individuals received careful examinations by our retina doctors, as they were the first-class relatives of severe FEVR patients with bilateral retinal folds. All cases were asymptomatic; however, the avascular zone of peripheral retinas and neovascular proliferations or diffuse leakage of dye was found by FFA.

In our study, we found and described three retinal/optic subtle changes in the posterior poles of FEVR patients with a fundus that is conventionally considered “normal” in appearance. First, we measured the size of the optic disc. It is important to evaluate the optic disc size because it affects the susceptibility of several optic nerve diseases such as glaucoma. Individuals with smaller optic discs are more likely to have glaucoma than those with larger discs. In the present study, we found that the optic disc is smaller in mild FEVR eyes than in controls. The mean size is 1605.34 ± 21.39 mm in FEVR eyes and 1733.39 ± 250.60 mm μ in healthy controls. The finding of subtle differences in the optic nerve size of FEVR individuals and controls has only been reported in Boonstra’s research. They also found smaller diameters in FEVR patients than in controls with diabetic retinopathy, which is consistent with our present study. However, all of the probands and family members with mild or severe FEVR were included in their study, while in ours, only asymptomatic mild individuals were employed. Moreover, both the horizontal and vertical diameters were smaller in FEVR patients in their study. In the present one, we found a dramatically smaller horizontal diameter in asymptomatic FEVR patients than controls and a similar vertical diameter. Our results suggested that even in asymptomatic FEVR, the development of the optic disc, especially the horizontal size, is abnormal. The reason for the smaller optic nerve size remains unknown. It might be a mild hypoplasia associated with FEVR itself, or the result of macular dragging. More research should be performed to identify the underlying mechanisms.

In addition, by means of fundus photographs, the DM distance was increased in FEVR patients compared with healthy controls. We found that DM/DD ratio was a more valuable tool to estimate the distance. In our study, the DM/DD was significantly larger in FEVR patients (3.49 ± 0.95) than in healthy controls (2.73 ± 0.28). In 1987, the normal value of the DM/DD ratio was 2.67 and increased in some diseases such as optic nerve hypoplasia. In our group of FEVR individuals, the DM/DD ratio was (2.73 ± 0.28) in healthy controls, which is quite similar to that reported in the literature, while in mild FEVR individuals, the DM/DD ratio increased to (3.49 ± 0.95), which is much higher than that in healthy controls. It is also much higher than the value reported in Boonstra’s study (2.89). However, the definition of DM/DD differs in the two studies. Boonstra defines DM/DD as half of the horizontal optic diameter plus the distance between the temporal margin of the optic disc and the center of the macular fovea (1/2 × D + B in Fig. 2), which is shorter than ours (shown in blue in Fig. 2). We think the horizontal distance only reflects the horizontal dragging of macula in (most patients, temporal), but not related to vertical dislocation, and it could not be well defined in some patients with intorsion or extorsion. Thus, we used a modified method to measure DM/DD to reveal both the horizontal and vertical ectopia of macula. The elongated DM/DD shows that although the visual acuity is normal in these patients, there is some subtle macular dragging, or ectopia of the macula due to the delay or absence of peripheral vascularization. In these patients, it is necessary to carefully examine the peripheral retinas to identify possible vessel abnormalities.

Finally, and most importantly, a new clinical feature of FEVR was observed in our study. We found that FEVR patients always have more retinal vessels radiating from the optic disc. To our knowledge, this is the first time the number of retinal vessels in these patients has been described and quantified. In our previous study (unpublished data), we used two circles, PIRC and PORC, which have a diameter of two and four times that of the optic disc and are centered on the center of the optic disc, as well as PTOA and PIA, defined as the part of the circle between the retinal temporal superior and temporal inferior branch vein, to quantify the number of vessels radiating from the optic disc. We found significantly more retinal vessels radiating from the optic disc compared to the healthy controls. The number of vessels crossing with PIRC and PORC, especially in the temporal side (PTIA and PTOA), was higher than that in healthy controls statistically. We also found an excellent correlation between the inner circle and the outer circle, and to simplify the measurement strategy, only the inner circle was used in the present study. Interestingly, in this study, we further confirmed that more vessels radiated from the optic nerve in FEVR patients than in controls.

An early diagnosis of FEVR is important for adequate genetic counseling as well as the prevention and treatment of complications that occur, predominantly at a young age. However, it is more difficult to observe the periphery of the retina, compared with the observation of the posterior pole. Our study showed that the conventional normal appearance of the posterior retina is, in fact, not normal. The three features of the posterior retina, including a smaller optic disc, a relatively large DM/DD, and more retinal vessels radiating from the optic disc, are detectable, although subtle, with the quantitative analysis used in our study. Therefore, the finding of subtle morphometric changes in the posterior pole may be an additional sign of FEVR, and thus provide us with important clues for the diagnosis of FEVR.

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