



Preferred Retinal Locus in Juvenile Macular Dystrophy

✉ Murat Erbezi¹, ✉ Zühal Özen Tunay², ✉ Taylan Öztürk³

¹Private Practice, İzmir, Türkiye

²TOBB University of Economics and Technology Faculty of Medicine, Department of Ophthalmology, Ankara, Türkiye

³Tinaztepe University Faculty of Medicine, Department of Ophthalmology, İzmir, Türkiye

Abstract

Objectives: To evaluate foveal lesion and preferred retinal locus (PRL) locations and their effects on visual acuity in juvenile macular dystrophy (JMD) patients.

Materials and Methods: In this retrospective study, 14 JMD patients (28 eyes) with bilateral central vision loss were examined using scanning laser ophthalmoscope/optical coherence tomography. Best-corrected visual acuity (BCVA), dimensions and location of the macular lesion, PRL location, and PRL stability were evaluated.

Results: Mean BCVA was 0.84 ± 0.17 logarithm of the minimum angle of resolution. PRL was superiorly located in 64.3% of eyes and nasally located in 35.7%. PRL location was significantly associated with patient age ($r=0.541$, $p=0.002$); nasally located PRLs were more common in younger patients (mean age 15.1 ± 2.8 years) while superiorly located PRLs were more common in older patients (mean age 22.4 ± 6.9 years). Superiorly located PRLs were significantly closer to the fovea than nasally located PRLs ($p=0.014$). Visual acuity worsened as lesion size increased and PRL-fovea distance increased. PRL-fovea distance was longer in younger patients and positively correlated with lesion dimensions and PRL-lesion distance.

Conclusion: In JMD patients, PRLs are predominantly located superiorly or nasally. In younger patients, PRLs are typically located nasally and farther from the fovea, with poorer visual acuity compared to older patients. Cortical adaptation mechanisms may play a role in changing PRL location with age. Understanding PRL characteristics in JMD is crucial for developing effective low-vision rehabilitation strategies.

Keywords: Macula, juvenile macular degeneration, central scotoma, low vision

Introduction

Juvenile macular dystrophy (JMD) is characterized by bilateral central vision loss due to macular lesions that cause central scotoma and severely affect foveal function.^{1,2} As a compensatory mechanism, patients frequently develop eccentric fixation areas, known as preferred retinal loci (PRLs). These are healthier parts of the eccentric retina used as alternative fixation points for visual tasks like reading and identifying faces and objects.³ Crossland and Rubin⁴ defined PRLs as “one or more circumscribed regions of functioning retina, repeatedly aligned with a visual target for a specified task, that may also be used for attentional deployment and as the oculomotor reference.” The location and stability of PRLs play a critical role in determining visual acuity, fixation stability, and rehabilitation outcomes.^{5,6}

Although it has been recognized that a PRL can be positioned differently in various macular pathologies or for different visual tasks, detailed characterization of PRL patterns in JMD patients remains limited. Microperimetry has emerged as a valuable tool for evaluating the location and stability of fixation in these patients.^{2,7} This study aimed to fill this knowledge gap by retrospectively evaluating foveal lesion and PRL locations and their effects on visual acuity in JMD patients assessed with scanning laser ophthalmoscope (SLO)/optical coherence tomography (OCT).

Materials and Methods

The study protocol adhered to the tenets of the Declaration of Helsinki, with approval obtained from the Ethics Committee of Dokuz Eylül University (date: 23.06.2021, approval number: 2021/19-22 [6371-GOA]). We retrospectively evaluated the records of JMD patients referred to our clinic for low-vision rehabilitation. Informed consent was waived due to the retrospective nature of the study. Included patients were below 35 years of age with bilateral impairment of central vision due to macular lesions. We excluded patients with other eye diseases

Cite this article as: Erbezi M, Özen Tunay Z, Öztürk T. Preferred Retinal Locus in Juvenile Macular Dystrophy. Turk J Ophthalmol. 2025;55:239-244

Address for Correspondence: Murat Erbezi, Private Practice, İzmir, Türkiye
E-mail: muraterbezi@gmail.com ORCID-ID: orcid.org/0000-0003-2163-2157

Received: 29.05.2025 Accepted: 03.09.2025

DOI: 10.4274/tjo.galenos.2025.73404

affecting visual acuity, those with a family history of other inherited systemic or retinal diseases, and those with incomplete records. In total, 14 JMD patients (28 eyes) with central vision loss were enrolled.

Distance best-corrected visual acuity (BCVA) was evaluated using the Early Treatment Diabetic Retinopathy Study Chart (Lighthouse, Long Island, NY, USA), and the results were expressed as the logarithm of the minimum angle of resolution (logMAR).

All patients were evaluated monocularly with an Optos SLO/OCT/microperimetry device (Optos, Florida, USA). Previous studies have also employed SLOs and SLO-based microperimetry to analyze PRL features in hereditary macular diseases such as Stargardt disease.^{8,9,10,11,12,13} JMD-related lesions and PRLs were assessed at the beginning of their low-vision clinical evaluation. For this purpose, patients were asked to fixate on a 2° cross target for 5 seconds. The device software continuously tracked fixation while the examiner simultaneously observed the fundus and fixation behavior. The system displayed fixation points as a cluster of cross marks on the fundus image. The dispersion of these marks indicated the fixation area. The greatest distance between any two marks was taken as the measure of fixation stability, with larger values reflecting greater instability of the PRL. This approach, although different from the bicurve ellipse area or percentage-within-1°/2° methods, has been applied in previous clinical studies (Figure 1).⁷

Lesion size was assessed by measuring the largest vertical and horizontal diameters, and the surface area was calculated under

the assumption of an ellipsoid shape, providing a standardized comparison across patients.

We marked the fovea as 15.5 degrees horizontally and 1.3 degrees vertically from the center of the optic disc.¹⁴ Considering the fovea as the center, we divided the retina into quadrants and classified PRL location relative to the fovea as superior (from 45°-135°), inferior (225°-315°), temporal (135°-225°), or nasal (315°-45°) (Figure 2).

Measurements were taken in units of degrees with the built-in caliper, and the units were converted to millimeters, considering one degree of visual angle equals 288 µm on the retina.¹⁵ The same physician conducted all evaluations to minimize variation in the measurements.

Statistical Analysis

SPSS version 22.0 statistical software (IBM Corp., Armonk, NY) was used for statistical analyses. The Shapiro-Wilk normality test assessed distribution uniformity. For non-normally distributed data, parametric tests were enabled through logarithmic correction. Non-parametric data were expressed as medians and ranges, and parametric data as mean ± standard deviation. P values <0.05 were considered statistically significant. Pearson correlation analysis, Student's t-tests, and chi-square test were used for statistical analyses. Pearson correlation analysis examined relationships among lesion dimensions, PRL location and stability, and logMAR BCVA.

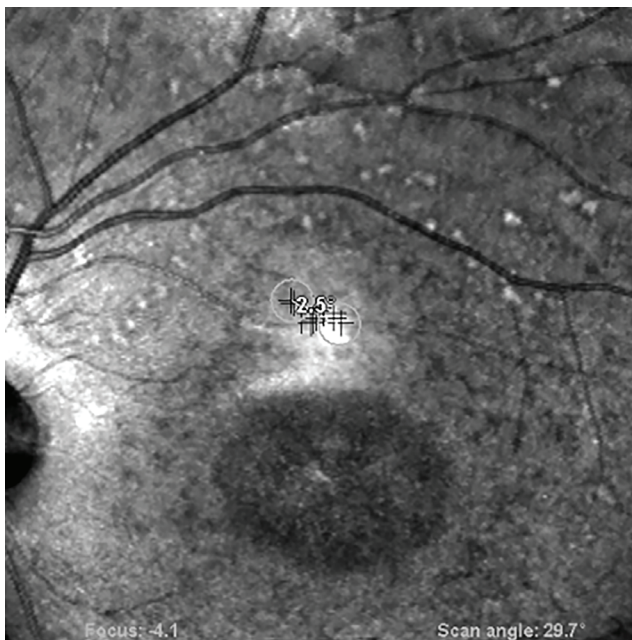


Figure 1. Example of fixation stability measurement in a patient with juvenile macular dystrophy. Fixation points recorded during a 5-second task are displayed as cross marks superimposed on the fundus image. The dispersion of the marks indicates fixation stability, quantified as the maximum distance between the two most distant points

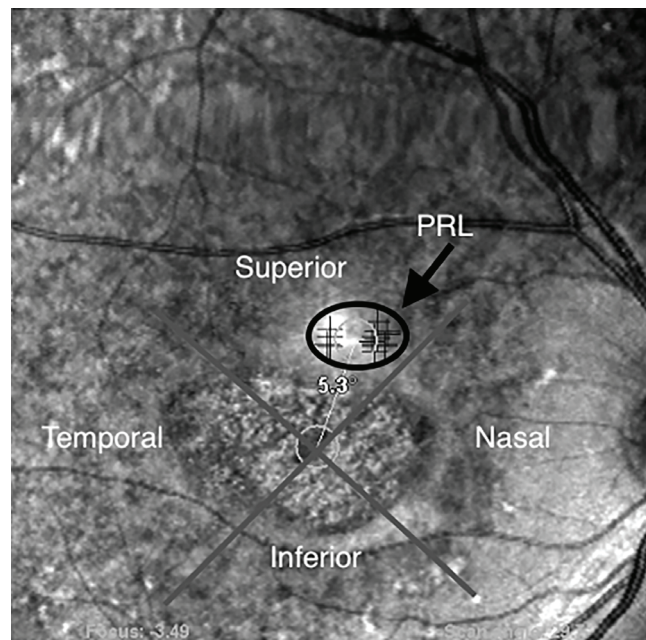


Figure 2. Determination of preferred retinal locus (PRL) location relative to the fovea in a patient with juvenile macular dystrophy. The fovea was marked at 15.5° horizontally and 1.3° vertically from the center of the optic disc. Using the fovea as the reference point, the retina was divided into four quadrants: superior (45°-135°), inferior (225°-315°), temporal (135°-225°), and nasal (315°-45°). Each PRL was classified according to its location in one of these quadrants

Results

Among the 14 patients, 8 were male and 6 female, with a mean age of 19.8 ± 6.8 years (range, 12-34). All patients had significant loss of central visual acuity due to JMD. The mean BCVA was 0.84 ± 0.17 logMAR (range, 0.52-1.15). Descriptive statistics, including vertical lesion size, horizontal lesion size, lesion area, distance from edge of lesion to PRL, distance from anatomic fovea to PRL, and PRL stability are given in [Table 1](#).

Eccentric fixation was present in all examined eyes. Importantly, each eye demonstrated a single dominant PRL during the 5-second fixation task, although the possibility of secondary PRLs for other visual tasks cannot be excluded. PRL was superiorly located in 18 eyes (64.3%) and nasally located in 10 eyes (35.7%). PRL location was significantly correlated with patient age (point-biserial correlation, $r=0.541$, $p=0.002$). The mean age was 15.1 ± 2.8 years in patients with nasally located PRLs and 22.4 ± 6.9 years in patients with superiorly located PRLs.

In the 7 adolescent patients (10-18 years of age), PRLs were nasally located in both eyes, except in one patient who had a nasally located PRL in one eye and a superiorly located PRL in the other (dominant) eye. PRLs were superiorly located in both eyes of all 7 young adults (19-34 years old), except in one patient who had a nasally located PRL in the dominant eye and a superiorly located PRL in the non-dominant eye.

Superiorly located PRLs were significantly closer to the fovea than nasally located PRLs ($p=0.014$). The mean PRL-fovea distance was 10.1 ± 3.20 degrees for nasally located PRLs and 6.90 ± 2.44 degrees for superiorly located PRLs. PRL location and PRL stability were not statistically significantly related (Student's *t*-test, $p=0.071$). PRL location was not associated with BCVA, horizontal lesion dimension, vertical lesion dimension, or PRL-lesion distance ($p=0.098$, 0.195, 0.066, and 0.093, respectively).

Pearson correlation analysis revealed that logMAR BCVA was positively correlated with the vertical ($p=0.001$, $r=0.573$) and horizontal ($p=0.002$, $r=0.565$) dimensions of the foveal

lesion, elliptic surface area of the lesion ($p=0.001$, $r=0.589$), and PRL-fovea distance ($p=0.009$, $r=0.487$). This indicates that visual acuity worsened with larger lesion size and greater PRL-fovea distance. All statistically significant associations and correlation coefficients are summarized in [Table 2](#).

PRL-fovea distance and age were negatively correlated ($p=0.018$, $r=-0.443$), indicating greater distances in younger patients. PRL-fovea distance was positively correlated with horizontal lesion size ($p=0.001$, $r=0.581$), vertical lesion size ($p<0.001$, $r=0.745$), lesion area ($p<0.001$, $r=0.684$), PRL-lesion distance ($p<0.001$, $r=0.800$), and BCVA (logMAR) ($p=0.009$, $r=0.487$). PRL-fovea distance and PRL stability were not correlated ($p=0.741$, $r=-0.065$).

The elliptic area of the lesion was positively correlated with PRL-fovea distance ($p<0.001$, $r=0.684$) and BCVA (logMAR) ($p=0.001$, $r=0.589$), indicating that in patients with larger macular lesions, the PRL was located farther from the fovea and visual acuity was worse. There was no statistically significant correlation between PRL stability and any measurement.

Discussion

Our study revealed that in JMD patients, PRLs are predominantly located superiorly (64.3%) or nasally (35.7%), with PRL location significantly correlated with patient age. Patients younger than 18 years (mean age 15.1 years) typically exhibited nasally located PRLs, while young adults (mean age 22.4 years) more commonly had superiorly located PRLs. Additionally, superior PRLs were significantly closer to the fovea compared to nasal PRLs, though PRL location did not correlate with visual acuity or lesion dimensions.

Our findings regarding PRL location align with previous research. Verdina et al.¹⁶ reported superiorly located PRLs in 86% of JMD patients and nasally located PRLs in 9.6%.

Table 1. Measurements of the size and location of the macular lesion in patients with juvenile macular degeneration (n=28)

	Mean $\pm$ SD	Range
Vertical lesion size (°)	8.08 ± 3.40	2.90-15.10
Horizontal lesion size (°)	9.73 ± 3.71	2.90-16.40
Vertical lesion size (mm)	2.33 ± 0.98	0.84-4.35
Horizontal lesion size (mm)	2.80 ± 1.07	0.84-4.72
Elliptical lesion area (mm ²)	5.82 ± 4.24	0.55-16.12
PRL-lesion distance (°)	4.01 ± 1.72	2.10-8.60
PRL-lesion distance (mm)	1.15 ± 0.50	0.60-2.48
PRL-fovea distance (°)	8.03 ± 3.09	3.50-14.50
PRL-fovea distance (mm)	2.31 ± 0.89	1.01-4.18
Fixation stability (°)	2.15 ± 1.43	0.50-6.40
PRL: Preferred retinal locus, SD: Standard deviation		

Table 2. Correlations between visual function, lesion characteristics, and preferred retinal locus parameters in patients with juvenile macular dystrophy

Variables	p value	r
BCVA (logMAR) vs. vertical lesion size	0.001	0.573
BCVA (logMAR) vs. horizontal lesion size	0.002	0.565
BCVA (logMAR) vs. lesion surface area	0.001	0.589
BCVA (logMAR) vs. PRL-fovea distance	0.009	0.487
PRL-fovea distance vs. age	0.018	-0.443
PRL-fovea distance vs. horizontal lesion size	0.001	0.581
PRL-fovea distance vs. vertical lesion size	<0.001	0.745
PRL-fovea distance vs. lesion surface area	<0.001	0.684
PRL-fovea distance vs. PRL-lesion distance	<0.001	0.800
PRL-fovea distance vs. BCVA (logMAR)	0.009	0.487
Lesion surface area vs. BCVA (logMAR)	0.001	0.589
Lesion surface area vs. PRL-fovea distance	<0.001	0.684

Pearson correlation coefficients (r) and corresponding p values are reported. BCVA: Best corrected visual acuity, logMAR: Logarithm of the minimum angle of resolution, PRL: Preferred retinal locus

Similarly, Chiang et al.¹⁷ found superiorly located PRLs in 48.3% of 59 JMD patients. Sunness et al.¹¹ reported that PRLs were located superiorly in 90% of patients with Stargardt disease, though their study population was older (mean age 34.2 years) than ours (mean age 19.8 years).

The PRL characteristics we observed in JMD differ from those typically seen in age-related macular degeneration (AMD). While AMD patients usually develop eccentric PRLs located at the border of the atrophic macular scar,^{7,18} our JMD patients showed PRLs at a greater distance from the lesion edge. The mean eccentric PRL-lesion distance in our JMD patients was 4.01 ± 1.72 degrees, similar to the 4.59 ± 2.36 degrees reported by Verdina et al.¹⁶, but notably larger than the 2.15-2.74 degrees typically reported in AMD patients.^{7,16,19,20} This suggests that a transition zone between the lesion and the PRL region is characteristic of JMD.

Interpretation and Implications

Superiorly located PRLs appear more advantageous for important visual tasks like reading and mobility. When the PRL is located above the lesion, the scotoma is positioned in the lower visual field, allowing unobstructed viewing of text lines during reading.^{21,22,23,24,25,26} Our finding that superiorly located PRLs were more common in older patients suggests that cortical adaptation mechanisms may play a role in PRL development and optimization over time.^{13,26}

The negative correlation between age and PRL-fovea distance, with younger patients exhibiting PRLs farther from the fovea and poorer visual acuity, likely reflects underlying structural differences. In our cohort, younger patients generally had larger lesion sizes and longer PRL-fovea distances, both of which were strongly correlated with worse BCVA. This suggests that the reduced visual acuity in younger patients is not solely age-related, but is mediated by greater anatomical disruption of the central retina and less efficient fixation adaptation. As expected, increased lesion size and PRL-fovea distance were associated with decreased visual acuity, confirming that retinal sensitivity decreases with increasing distance from the fovea, as previously reported in studies of eccentric PRLs in both JMD and AMD patients.^{7,11,19,27}

Our finding that superiorly located PRLs were more common in older patients suggests that cortical adaptation mechanisms contribute to PRL development and optimization over time. This interpretation is supported by evidence that visual cortical networks reorganize in response to altered input, even beyond the critical period of visual development. Cheung and Legge¹³ demonstrated that patients with central vision loss engage both perceptual and oculomotor recalibration processes, enabling the emergence of more functionally advantageous PRLs. More recently, Kolawole et al.²⁸ used high-resolution imaging to show that eccentric PRLs are not merely anatomically determined, but represent functionally optimized loci shaped by higher-order cortical processing. These findings provide a neurofunctional basis for the age-related PRL relocation we observed in JMD patients.

From a rehabilitation perspective, PRL location has substantial clinical implications. Spontaneously developed PRLs may be suboptimal (e.g., unstable, located far from the fovea, or positioned in areas with reduced retinal sensitivity), necessitating specific interventions. Eccentric viewing training facilitates the use of more effective peripheral retinal loci for visual tasks and has long been a cornerstone of functional rehabilitation in patients with central vision loss. Early studies emphasized the importance of behavioral training in stabilizing PRL usage and improving visual performance.^{23,29,30}

More recently, targeted training approaches combining perceptual and oculomotor exercises have been shown to accelerate the establishment of a stable pseudofovea,²⁴ shedding light on the underlying neuroplastic mechanisms that contribute to PRL optimization in conditions like JMD.³¹ In line with these advancements, microperimetry-based acoustic biofeedback training has also been shown to enhance PRL stability and reading performance in patients with central scotoma.³² In addition, optical strategies such as prism relocation may help shift fixation toward more functionally advantageous loci. Incorporating these approaches into low-vision rehabilitation programs for JMD could improve both distance and near vision performance.

Study Limitations

This study has several limitations. First, as a retrospective study with a modest sample size, our findings should be interpreted with caution and validated in larger, prospective cohorts. Second, all measurements were obtained monocularly. In real-life viewing conditions, binocular interactions and dominance effects can influence PRL characteristics and may yield different functional outcomes. Third, we did not assess retinal sensitivity values in decibels, which would have provided additional information about the functional capacity of the eccentric fixation areas. Fourth, our analysis did not include near-vision performance parameters such as reading acuity, critical print size, maximum reading speed, and reading ease. These measures are particularly relevant for evaluating the everyday functional implications of PRL location and stability.

Future studies should therefore aim to incorporate binocular assessments, detailed retinal sensitivity mapping, and standardized continuous-text reading tests in addition to traditional visual acuity outcomes. Such a comprehensive evaluation would provide a more complete understanding of PRL adaptation and its clinical significance in JMD.

Conclusion

This study demonstrates that in JMD, PRLs are most often positioned superiorly or nasally, and their location is significantly correlated with patient age. Younger patients tend to exhibit nasally located PRLs that lie farther from the fovea, a pattern associated with larger lesion sizes, greater PRL-fovea distances, and consequently poorer visual acuity. In contrast, older patients more commonly show superior PRLs, which are functionally advantageous for tasks such

as reading and mobility. These findings support the role of cortical adaptation mechanisms in the age-related relocation and optimization of PRLs, underscoring the potential benefit of harnessing or guiding this adaptation in clinical practice. From a rehabilitation standpoint, when spontaneous PRLs are unstable or suboptimally located, targeted interventions such as eccentric viewing training, combined perceptual-oculomotor protocols, and optical strategies like prism relocation should be considered to promote the development of a stable and effective pseudofovea. Although near-vision parameters were not assessed in this retrospective study, future work should integrate reading performance measures to better capture the functional implications of PRL characteristics in daily life. In summary, recognizing the distinct PRL patterns and their relationship with age, lesion size, and visual function in JMD is essential for designing individualized, evidence-based low-vision rehabilitation strategies that optimize visual outcomes in this young patient population.

Ethics

Ethics Committee Approval: The study protocol adhered to the tenets of the Declaration of Helsinki, with approval obtained from the Ethics Committee of Dokuz Eylül University (date: 23.06.2021, approval number: 2021/19-22 [6371-GOA]).

Informed Consent: Retrospective study.

Declarations

Authorship Contributions

Surgical and Medical Practices: M.E., Concept: M.E., Z.Ö.T., T.Ö., Design: M.E., Z.Ö.T., T.Ö., Data Collection or Processing: M.E., Z.Ö.T., T.Ö., Analysis or Interpretation: M.E., Z.Ö.T., T.Ö., Literature Search: M.E., Z.Ö.T., T.Ö., Writing: M.E., Z.Ö.T.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

References

- Altschwager P, Ambrosio L, Swanson EA, Moskowitz A, Fulton AB. Juvenile macular degenerations. *Semin Pediatr Neurol.* 2017;24:104-109.
- Bethlehem RA, Dumoulin SO, Dalmaijer ES, Smit M, Berendschot TT, Nijboer TC, Van der Stigchel S. Decreased fixation stability of the preferred retinal location in juvenile macular degeneration. *PLoS One.* 2014;9:e100171.
- Schönbach EM, Strauss RW, Kong X, Muñoz B, Ibrahim MA, Sunness JS, Birch DG, Hahn GA, Nasser F, Zrenner E, Sadda SR, West SK, Scholl HPN; ProgStar Study Group. Longitudinal changes of fixation location and stability within 12 months in stargardt disease: ProgStar report no. 12. *Am J Ophthalmol.* 2018;193:54-61.
- Crossland MD, Rubin GS. The use of an infrared eyetracker to measure fixation stability. *Optom Vis Sci.* 2002;79:735-739.
- Altınbay D, İdil ŞA. Current approaches to low vision (Re)habilitation. *Türk J Ophthalmol.* 2019;49:154-163.
- Altınbay D, İdil ŞA. Fixation stability and preferred retinal locus in advanced age-related macular degeneration. *Türk J Ophthalmol.* 2022;52:23-29.
- Erbezci M, Öztürk T. Preferred retinal locus locations in age-related macular degeneration. *Retina.* 2018;38:2372-2378.
- Chun R, Fishman GA, Collison FT, Stone EM, Zernant J, Allikmets R. The value of retinal imaging with infrared scanning laser ophthalmoscopy in patients with stargardt disease. *Retina.* 2014;34:1391-1399.
- Anastasakis A, Fishman GA, Lindeman M, Genead MA, Zhou W. Infrared scanning laser ophthalmoscopy imaging of the macula and its correlation with functional loss and structural changes in patients with stargardt disease. *Retina.* 2011;31:949-958.
- Timberlake GT, Mainster MA, Peli E, Augliere RA, Essock EA, Arend LE. Reading with a macular scotoma. I. Retinal location of scotoma and fixation area. *Invest Ophthalmol Vis Sci.* 1986;27:1137-1147.
- Sunness JS, Schuchard RA, Shen N, Rubin GS, Dagnelie G, Haselwood DM. Landmark-driven fundus perimetry using the scanning laser ophthalmoscope. *Invest Ophthalmol Vis Sci.* 1995;36:1863-1874.
- Liu H, Bittencourt MG, Sophie R, Sepah YJ, Hanout M, Rentiia Z, Annam R, Scholl HP, Nguyen QD. Fixation stability measurement using two types of microperimetry devices. *Transl Vis Sci Technol.* 2015;4:3.
- Cheung SH, Legge GE. Functional and cortical adaptations to central vision loss. *Vis Neurosci.* 2005;22:187-201.
- Tarita-Nistor L, González EG, Markowitz SN, Steinbach MJ. Fixation characteristics of patients with macular degeneration recorded with the mp-1 microperimeter. *Retina.* 2008;28:125-133.
- Drasdo N, Fowler CW. Non-linear projection of the retinal image in a wide-angle schematic eye. *Br J Ophthalmol.* 1974;58:709-714.
- Verdina T, Greenstein VC, Sodi A, Tsang SH, Burke TR, Passerini I, Allikmets R, Virgili G, Cavallini GM, Rizzo S. Multimodal analysis of the preferred retinal location and the transition zone in patients with stargardt disease. *Graefes Arch Clin Exp Ophthalmol.* 2017;255:1307-1317.
- Chiang WY, Lee JJ, Chen YH, Chen CH, Chen YJ, Wu PC, Fang PC, Kuo HK. Fixation behavior in macular dystrophy assessed by microperimetry. *Graefes Arch Clin Exp Ophthalmol.* 2018;256:1403-1410.
- Schuchard RA. Preferred retinal loci and macular scotoma characteristics in patients with age-related macular degeneration. *Can J Ophthalmol.* 2005;40:303-312.
- Sunness JS, Applegate CA, Haselwood D, Rubin GS. Fixation patterns and reading rates in eyes with central scotomas from advanced atrophic age-related macular degeneration and Stargardt disease. *Ophthalmology.* 1996;103:1458-1466.
- Greenstein VC, Santos RA, Tsang SH, Smith RT, Barile GR, Seiple W. Preferred retinal locus in macular disease: characteristics and clinical implications. *Retina.* 2008;28:1234-1240.
- Messias A, Reinhard J, Velasco e Cruz AA, Dietz K, MacKeben M, Trauzettel-Klosinski S. Eccentric fixation in Stargardt's disease assessed by Tübingen perimetry. *Invest Ophthalmol Vis Sci.* 2007;48:5815-5822.
- Fine EM, Rubin GS. Reading with simulated scotomas: attending to the right is better than attending to the left. *Vision Res.* 1999;39:1039-1048.
- Nilsson UL, Frennesson C, Nilsson SE. Patients with AMD and a large absolute central scotoma can be trained successfully to use eccentric viewing, as demonstrated in a scanning laser ophthalmoscope. *Vision Res.* 2003;43:1777-1787.
- Nguyen NX, Stockum A, Hahn GA, Trauzettel-Klosinski S. Training to improve reading speed in patients with juvenile macular dystrophy: a randomized study comparing two training methods. *Acta Ophthalmol.* 2011;89:e82-e88.
- Petre KL, Hazel CA, Fine EM, Rubin GS. Reading with eccentric fixation is faster in inferior visual field than in left visual field. *Optom Vis Sci.* 2000;77:34-39.
- Sullivan B, Walker L. Comparing the fixational and functional preferred retinal location in a pointing task. *Vision Res.* 2015;116:68-79.
- Fletcher DC, Schuchard RA. Preferred retinal loci relationship to macular scotomas in a low-vision population. *Ophthalmology.* 1997;104:632-638.
- Kolawole OU, Bensinger E, Wong J, Rinella N, Foote KG, Zhou H, Wang RK, Duncan JL, Roorda A. High resolution imaging and fixation analysis of eccentric preferred retinal loci in macular diseases. *Invest Ophthalmol Vis Sci.* 2025;66:18.

29. Holocomb JG, Goodrich GL. Eccentric viewing training. *J Am Optom Assoc.* 1976;47:1438-1443.
30. Goodrich GL, Mehr EB. Eccentric viewing training and low vision aids: current practice and implications of peripheral retinal research. *Am J Optom Physiol Opt.* 1986;63:119-126.
31. Liu R, Kwon M. Integrating oculomotor and perceptual training to induce a pseudofovea: A model system for studying central vision loss. *J Vis.* 2016;16:10.
32. Sahli E, Altinbay D, Bingol Kiziltunc P, Idil A. Effectiveness of low vision rehabilitation using microperimetric acoustic biofeedback training in patients with central scotoma. *Curr Eye Res.* 2021;46:731-738.