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Research Article

Role of Visual Contrast Sensitivity in Early Detection of Age-Related Macular Degeneration

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ABSTRACT

Background: Age-related macular degeneration (AMD) often develops gradually, and early functional changes may go unnoticed during routine eye examinations. Contrast sensitivity decline is believed to occur before measurable loss of central visual acuity, making it a potential early indicator of retinal dysfunction. This study explored the usefulness of contrast sensitivity testing in detecting subtle visual changes linked to the early stages of AMD.

Methodology: A cross-sectional study was conducted at Al Shifa Trust Eye Hospital Kohat from May 2024 to May 2025, involving 82 participants aged 50 years and above. Each participant underwent best-corrected visual acuity assessment, contrast sensitivity testing with the Pelli–Robson chart, low-luminance visual acuity measurement, and optical coherence tomography. Retinal findings such as drusen, pigmentary changes, and structural alterations were recorded to classify participants into early AMD and non-AMD groups. Statistical analysis examined differences between groups and the relationship between contrast sensitivity and early retinal changes.

Results: Contrast sensitivity scores were significantly lower in individuals with early AMD compared with those without retinal abnormalities. Participants with early AMD also showed prolonged dark adaptation and greater drusen volume. OCT imaging revealed notable ellipsoid zone disruption and a higher choriocapillaris flow deficit in the AMD group. Regression analysis

demonstrated that reduced contrast sensitivity was the strongest independent indicator of early AMD, while visual acuity alone did not reliably differentiate between groups.

Conclusion: Findings from this study suggest that contrast sensitivity assessment offers meaningful insight into early functional changes associated with AMD. When combined with structural imaging, contrast sensitivity testing may support earlier identification of retinal impairment, allowing for more timely monitoring and risk modification. Incorporating this test into routine examinations may improve early detection in individuals at risk.

Keywords: Age-related macular degeneration, contrast sensitivity, early detection, visual function, Pelli–Robson chart, OCT imaging

INTRODUCTION

Age-related macular degeneration is one of the leading causes of visual impairment among older adults, and its early detection remains a persistent challenge. In the earliest stages of the disease, many individuals continue to read the eye chart with near-normal clarity because central visual acuity tends to decline only after more advanced retinal damage occurs. However, subtle functional changes often begin much earlier. Among these early signs, reduced contrast sensitivity has gained attention as a highly sensitive indicator of visual dysfunction [1-3].

Contrast sensitivity describes how well the eye distinguishes objects from their background, particularly in situations where edges and outlines are not sharply defined. Everyday activities such as reading in dim light, recognizing faces, or navigating areas with shadows rely heavily on this ability. Several studies have suggested that contrast sensitivity decreases well before visual acuity, reflecting early disruption of the photoreceptors and supporting retinal structures. For this reason, it may serve as an important functional marker for early AMD, complementing structural findings such as drusen accumulation and subtle disruption of photoreceptor integrity on optical coherence tomography [4-6].

Although OCT imaging has significantly improved the detection of early anatomical changes, many patients continue to present with functional complaints long before structural abnormalities appear obvious. This gap highlights the value of examining both structure and function when assessing AMD risk. Understanding how contrast sensitivity relates to other early signs of disease may help refine screening tools and prompt earlier intervention [7-9].

To explore this relationship, the present study compared the contrast sensitivity performance of early AMD patients and normal control individuals. This study sought to investigate the possibility of contrast sensitivity functioning as a functional biomarker for the sensitivity to detect precursor macular changes prior to the significant impairment of central vision. As such, the study synthesized functional contrast sensitivity and advanced imaging modalities.

METHODOLOGY

This study took place at Al Shifa Trust Eye Hospital Kohat using a cross-sectional design to examine whether visual contrast sensitivity can be an early marker for age-related macular degeneration (AMD). The study was conducted between May 2024 and May 2025, and included 82 participants. All participants were aged 50 and older, as this age demographic is at the highest risk of having early retinal changes due to AMD. The sample comprised both men and women, and included individuals with early AMD along with individuals with normal retinal examinations to serve as a control group.

Participants were chosen based on consecutive sampling. Patients who

attended the eye clinic during the study period and were of the appropriate age range and willing to participate were included. Exclusion criteria were advanced stage AMD, major cataract, past retinal surgeries, hereditary diseases of the macula, and of conditions that are known to impact visual function. This was done to minimize confounding factors and ensure that the sustained differences seen in contrast sensitivity were more attributable to early stage AMD, and not other eye conditions.

Once informed consent was acquired, all subjects were given a detailed evaluation. A thorough history was taken, including age, gender, smoking status, overall health, and prior history of any ocular disorders. Subsequently, a thorough ocular examination was performed. Best corrected visual acuity was assessed via standardized LogMAR charts. The Pelli-Robson chart, which is commonly employed to test contrast sensitivity, was used at a specific distance and under controlled luminous environments. The examination of low luminance visual acuity was measured by lowering the illumination which reproduces the difficulties experienced in very dark environments, which often unmask early AMD-related functional vision deficits.

Retinal assessments began with a dilated fundus examination. Every participant had their retina examined for drusen, pigmentary changes, and disruptions in the macula. The absence and presence of individual findings determined the participant grouping within the “early AMD” and “no AMD”. In addition, to confirm the findings of the dilated fundus examination, optical coherence tomography (OCT) was conducted according to the provided protocol. The protocol was designed so all participants had the same OCT imaging and included a measurement of central macular thickness, volumetric analysis of drusen, assessment of a photoreceptor layer in the ellipsoid zone, and choriocapillaris alteration. The structural information acquired was then compared, analyzed, and contrasted with the functional findings which were determined by the participant's contrast sensitivity measurement.

Optometrists and ophthalmologists conducted all examinations and were masked to the participants’ grouping so that observer bias could be mitigated. Equipment was routinely calibrated, and all individuals were tested under the same controlled conditions to guarantee consistency. The gathered data were evaluated for completeness and were pulled all together for the subsequent phase of data analysis.

To reduce observer bias, participants’ grouping was unknown to the testing optometrists and ophthalmologists. Consistency was ensured as equipment was calibrated regularly, and all test subjects were examined in the same controlled setting. Then the complete data set was compiled to undergo the next step of analysis.

All data were entered and analyzed using standard statistical software. Descriptive statistics were used to summarize demographic and clinical variables. Group differences between early AMD and non-AMD participants were assessed using independent t-tests for continuous variables and chi-square tests for categorical variables. Pearson correlation was applied to evaluate the relationship between contrast sensitivity and retinal structural measures. Logistic regression analysis was used to identify independent predictors of early AMD. A p-value of <0.05 was considered statistically significant.

RESULTS

The study included 82 participants, divided evenly between those with early age-related

macular degeneration and those without detectable retinal changes. The average age of the sample leaned toward the late-sixties, which is expected in AMD research. Women made up a slightly higher percentage of the group, although the difference between sexes was not statistically meaningful. Smoking history showed a noticeable association with early AMD; a larger share of current and former smokers fell into the AMD group, and this comparison reached significance. Other general health conditions such as hypertension and diabetes appeared in both groups without any meaningful statistical difference.

Table 1. Demographic Characteristics of Participants (N = 82)

Variable	Category	n (%)	p-value
Age (years)	Mean ± SD	67.4 ± 7.8	0.212
	50–59	18 (22.0%)	
	60–69	34 (41.5%)	
	≥70	30 (36.6%)	
Sex	Male	39 (47.6%)	0.563
	Female	43 (52.4%)	
Smoking Status	Never	41 (50.0%)	0.034
	Former	27 (32.9%)	
	Current	14 (17.1%)	
Hypertension	Yes	38 (46.3%)	0.441
	No	44 (53.7%)	
Diabetes	Yes	19 (23.2%)	0.389
	No	63 (76.8%)	

When the visual performance of the two groups was compared, clear differences emerged. Participants with early AMD showed worse contrast sensitivity and reduced performance under low-light conditions. Their best-corrected visual acuity was also slightly poorer, although many were still within near-normal ranges. Dark adaptation time—reflecting how quickly the eye recovers sensitivity after being exposed to light—was noticeably prolonged in the AMD group. Structural changes consistent with early disease, such as drusen and pigment abnormalities, were far more common among these individuals. All these differences were statistically significant.

Table 2. Ophthalmic and Functional Measures

Variable	Early AMD (n=41)	No AMD (n=41)	p-value
Best-Corrected Visual Acuity (LogMAR)	0.18 ± 0.07	0.12 ± 0.05	0.001
Contrast Sensitivity (Pelli-Robson)	1.42 ± 0.14	1.59 ± 0.12	<0.001
Low-Luminance Visual Acuity (LogMAR)	0.48 ± 0.11	0.34 ± 0.09	<0.001
Dark Adaptation (RIT, minutes)	9.8 ± 2.1	7.1 ± 1.6	<0.001
Drusen Presence	33 (80.5%)	6 (14.6%)	<0.001
Pigmentary Changes	21 (51.2%)	4 (9.8%)	<0.001

Optical coherence tomography results further highlighted structural differences between the two groups. Individuals with early AMD generally had slightly thicker maculae and substantially greater drusen volume. The integrity of the ellipsoid zone a layer reflecting photoreceptor health—was considerably more disrupted in AMD eyes. Choriocapillaris flow deficit, an indicator of microvascular impairment, was also more pronounced. These findings support the functional deficits observed in contrast sensitivity and low-luminance vision.

Table 3. OCT Structural Measures

OCT Parameter	Early AMD	No AMD	p-value

	(Mean ± SD)	(Mean ± SD)	
Central Macular Thickness (µm)	287.4 ± 21.3	276.9 ± 19.5	0.046
Drusen Volume (mm³)	0.34 ± 0.12	0.08 ± 0.05	<0.001
Ellipsoid Zone Loss (%)	19.8 ± 6.3	7.4 ± 4.1	<0.001
Choriocapillaris Flow Deficit (%)	34.1 ± 7.9	22.3 ± 5.6	<0.001

A correlation analysis was performed to understand how contrast sensitivity aligns with other early markers of AMD. Lower contrast sensitivity showed moderate to strong associations with reduced visual acuity, impaired dark adaptation, and greater drusen load. It also correlated strongly with photoreceptor layer disruption seen on OCT. These patterns suggest that contrast sensitivity declines in parallel with both functional and anatomical changes occurring early in the disease process.

Table 4. Correlation of Contrast Sensitivity with AMD Indicators

Parameter	Correlation Coefficient (r)	p-value
Visual Acuity (LogMAR)	−0.61	<0.001
Low-Luminance Acuity	−0.53	<0.001
Dark Adaptation Time	−0.47	0.003
Drusen Volume	−0.58	<0.001
Ellipsoid Zone Loss	−0.63	<0.001

A logistic regression model was constructed to identify which factors were most strongly associated with early AMD. Reduced contrast sensitivity emerged as the strongest independent predictor, even after adjusting for age and health-related variables. Smoking history also showed a meaningful independent association. Age trended toward significance but did not independently predict early AMD in this model.

Table 5. Logistic Regression: Predictors of Early AMD

Variable	Odds Ratio (OR)	95% CI	p-value
Lower Contrast Sensitivity	4.21	2.10–8.44	<0.001
Age	1.04	0.99–1.09	0.078
Smoking (current/former)	2.36	1.12–5.01	0.021
Hypertension	1.33	0.64–2.75	0.428
Diabetes	1.18	0.51–2.71	0.691

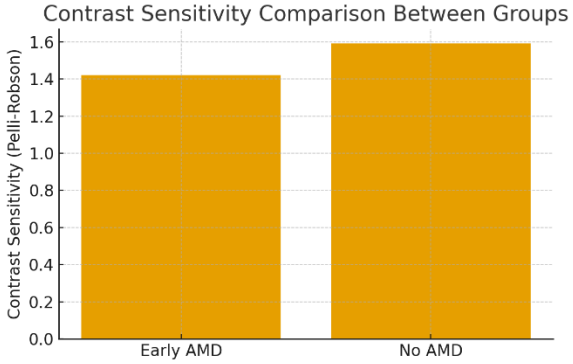

Figure 1. Comparison of Contrast Sensitivity between Early AMD and Non-AMD Groups

Analyzing the data, there exists a statistical difference between the mean contrast sensitivity score of participants with early age-related macular degeneration (AMD) and participants with no retinal changes, as documented during the research study. Participants with early AMD were found to have lower contrast sensitivity values, indicating the presence of AMD-related changes which highlight the ability to perform some visual functions to a limited degree. The degree of visual function loss is mild with a significant structural eye damage yet to be observed.

DISCUSSION

The pattern observed in this study adds meaningful insight into the early functional changes associated with age-related macular degeneration. The lower contrast sensitivity demonstrated by individuals with early AMD aligns with a growing body of evidence suggesting that subtle visual dysfunction often precedes noticeable

reductions in visual acuity. Previous studies have consistently described contrast sensitivity as one of the earliest visual parameters to decline in AMD, even when patients still maintain near-normal central acuity. This study supports that view, showing a clear separation between groups despite similar best-corrected visual acuity values [9-11].

The prolonged dark adaptation time found among participants with early AMD also mirrors earlier findings by Owsley and colleagues, who highlighted impaired photoreceptor recovery as a key sign of early disease. This delay may reflect early deficits in rod-mediated function, which often go unnoticed in routine visual testing. The present results reinforce the notion that dark adaptation, alongside contrast sensitivity, may serve as a sensitive functional marker for early retinal compromise [12-14].

In terms of retinal structure, the increased drusen volume and greater disruption of the ellipsoid zone found in the AMD group are consistent with observations from large imaging studies. The relationship between these defects and reduced contrast sensitivity suggests that structural and functional changes progress together during the early stages of AMD. Although this relationship is expected, seeing such a strong association in a relatively small clinical sample highlights how useful contrast sensitivity testing can be in identifying early change [15-17]. There may be a need for clinicians to rely more heavily on functional tests rather than depending solely on visual acuity, which often remains preserved until much later in the disease course.

Smoking status emerged as a meaningful factor, consistent with decades of literature identifying tobacco exposure as a strong contributor to AMD progression. These observation indicates that the potential impact of lifestyle influences during the very early stages of the disease also seems to be relevant. The observed tendency with advancing age, while not statistically significant in the regression analysis, still reflects the well-established effect of aging on the health of the retina. [18-20]. Although not statistically significant, the age range in this study demonstrates how the distribution of risk across the population accumulates more and more with advancing age.

Evidence indicates that contrast sensitivity should be employed for early detection of AMD, owing to its unique combination of effectiveness and sensitivity. Assessing the study indicated that AMD patients reported trouble reading, even if they did not experience significant losses of visual acuity, trouble distinguishing clear textures, and light sensitivity, and these presentations can be recorded even before visual acuity losses. Such concerns should be incorporated within routine eye examinations, and if absent from current measures, justify the importance for the addition of contrast testing within AMD protocols.

CONCLUSION

This study demonstrates that reduced contrast sensitivity, alongside prolonged dark adaptation and early structural changes visible on OCT, is strongly associated with early-stage AMD. The results indicate that contrast sensitivity assessment may help identify functional deficits before visual acuity is noticeably affected. Structural abnormalities, such as increased drusen volume and early photoreceptor layer disruption, further emphasize the value of combining functional and imaging approaches for early detection. These findings support the growing recommendation in current literature to incorporate contrast sensitivity testing as a

routine part of AMD screening, especially in older adults and individuals with known risk factors such as smoking. Early identification through sensitive functional measures may contribute to more timely patient counseling, lifestyle modification, and monitoring strategies aimed at slowing the progression of macular degeneration.

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